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The Precedence of Global Features in the Perception of Map Symbols

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U.S. Army
Research Institute for the Behavioral and Social Sciences

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This research investigated the role of global precedence in visual perceptual processing. Researchers evaluated the effect of global features on the speed and accuracy of detecting map symbols. The global precedence position suggests that perception proceeds temporally, through stages, from the recognition of global features to a more local, fine-grained analysis of individual elements.

The study was conducted to compare performance (speed and accuracy) in a symbol-alone condition with that in various symbol-plus-distractor conditions. Scaling techniques (Multidimensional Scaling Analysis and Hierarchical Cluster Analysis) were applied to an existing database of map symbols to categorize global (general) and local (detailed) features of the symbols. Following this, a detection task was performed to determine the level of interference in detecting target symbols of various global categories when

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distractor symbols were present. The response latency and accuracy measures from the detection study were analyzed using a one-way repeated measures ANOVA, followed by planned comparisons between target-distractor category means.

The research shows that the response latency measure discriminates well among symbol-distractor conditions, but the accuracy measure does not. First analysis of the data did not reflect the impact of global precedence in all cases. Further analysis revealed that local feature similarity played a more prominent role in discriminating symbol groups than was originally suspected. It is clear that the global precedence concept is a useful one in describing symbol populations in existence as long as the a priori scaling procedures used are precise enough to derive the global features.

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Human Performance Effectiveness and Simulation

FOREWORD

Military symbology is an integral part of the Army's network of communication. The U.S. Army Research Institute (ARI) has devoted a program of research to improving symbol detection and display. Researchers are working to determine hardware and software factors that affect performance and the types of information that should be displayed, and to develop a database of military symbols that can be continually updated.

The present study evaluated the feasibility of a serial model of visual processing. By comparing performance between a symbol-alone condition and various target-plus-distractor conditions, researchers found that speed of performance differed across conditions but that accuracy of performance did not. The serial model of visual processing was supported. The implications of these results will be combined with ongoing efforts at ARI to improve symbolic visual displays.

Edgar M. Johnson

EDGAR M. JOHNSON
Technical Director

THE PRECEDENCE OF GLOBAL FEATURES IN THE PERCEPTION OF MAP SYMBOLS

EXECUTIVE SUMMARY

Requirement:

To improve assimilation of visual symbolic information on military map displays, focusing on the role of global (high-level) and local (detailed) symbolic features as they impact operator detection performance.

Procedure:

Researchers evaluated the effect of global features on the speed and accuracy of detecting military map symbols in current use. Scaling techniques (Multidimensional Scaling Analysis and Hierarchical Cluster Analysis) were applied to an existing database of symbols to categorize global and local features. Following this, a detection task was performed to determine the level of interference in detecting target symbols when distractor symbols were present from the various global categories. The response latency and accuracy of identification of symbols was analyzed using a one-way repeated measures ANOVA design.

Findings:

The research shows that the response latency measure is a good discriminator of detection performance, but the accuracy measure is not. Additionally, the scaling techniques do not provide the needed definition of local features required to adequately predict performance in all cases. Further analysis revealed that local feature similarity played a more prominent role in discriminating symbol groups than had been originally suspected.

Utilization of Findings:

The results of this work will be applied to methods used to assess the utility of computer-generated map displays projected for use in Command, Control and Intelligence systems. It is clear that the global precedence concept is a viable one in describing symbol and graphic concepts to portray command and intelligence summaries, as long as the a priori scaling procedures used are made precise enough to derive the correct global and local features.

THE PRECEDENCE OF GLOBAL FEATURES IN THE PERCEPTION OF MAP SYMBOLS

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THE PRECEDENCE OF GLOBAL FEATURES IN THE PERCEPTION OF MAP SYMBOLS

INTRODUCTION

A large body of perceptual literature, beginning with the Gestalt theorists, indicates that pattern structure is perceptually significant in both natural and man-made symbols (Mach, 1897; Attneave, 1955; Julesz, 1971). Broadbent's analysis (1977) indicates that perceptual processing of visual patterns, such as symbols, is based on a "filtering" procedure, consisting of a series of passive-to-active or global-to-local stages. Navon (1977, 1981a) has proposed a "global precedence" hypothesis, which suggests further that the perceptual system first processes symbols globally, followed by a local, more "fine-grained" analysis. This research is an investigation of how global and local processing of visual stimuli affect the speed and accuracy of map symbol perception in a search and locate task. This is part of a trend to understand perceptual processing in the context of specific performance tasks. It addresses the role of symbol structure in detection on maps, which is critical for prescribing how symbols should be designed and placed on map backgrounds to portray military events. In addition, Navon's findings, which have been demonstrated with rather abstract forms and figures, are extended and made more generalizable. The current use of an applied symbol population provides a broader test of the global precedence idea, and allows greater predictability to other areas.

BACKGROUND

The Gestaltist's view of the perceptual system is that the inspection of a visual scene involves cognitive rules for perceptual organization. Since the visual environment is typically data rich, one attempt to explain perceptual organization is a "global minimum" principle, i.e., that we perceive the "simplest" of the alternative organizations available for the entire stimulus pattern being considered (Peterson & Hochberg, 1983). Certain "features" within the visual scene are seen as comprising a "figure," against which the rest of the stimulus information is "background." Pattern structures are seen in terms of "units," or perceptual "wholes." The essence of the position is that perceptual processing begins with a global whole to which local details are gradually added.

The perceptual advantage of figure over ground has been conceptualized in a number of ways (e.g. Wong & Weisstein, 1983). They have proposed that more attention is given to figure, whereas details are generally ignored. Because of greater attention, motion, contour, and displacement are more salient in a figure than in the background (Wong & Weisstein, 1983).

The Gestalt theorists described the figure as having a "thing-like" character, and being "more strongly structured and more impressive" (Koffka, 1935). This approach to figure and ground was not explored further theoretically in the context of perceptual processing

until quite recently when Julesz (1978) proposed that not only do different visual processes mediate the processing of figure and ground, but also that each analysis involves highly specialized functions.

It is also assumed that the extraction of global information proceeds more quickly than the extraction of details about a pattern, and some investigators characterize ground analysis as an "early warning system" for visual processing (Breitmeyer & Ganz, 1976; Calis & Leeuwenburg, 1981, Julesz, 1978). These investigators have equated figure and ground analysis to the examination of low and high spatial frequency channels of the visual system. This is in line with current theories of perception and cognition characterizing the human as an information processor, with various subsystems serving the master controller. The visual system is just one of these subsystems. According to these investigators, ground analysis has been thought to involve the low end of the frequency spectrum (Broadbent, 1977; Breitmeyer & Ganz, 1976).

Clearly the information processing emphasis in the experimental literature (Atkinson & Shiffrin, 1968; Neisser, 1967) has had an impact on perceptual theorizing. The position did not arise as a reaction against the traditional Gestalt viewpoint, but rather as a movement to incorporate the concepts of cognition, or processing activity, into perception. The basic idea is that perception is not an immediate outcome of environmental stimulation, (as suggested by the Gestaltists), but the result of processing over time, in a series of parallel or concurrent stages (Haber & Hershenson, 1980).

Applying the information processing view to early visual pattern processing, Broadbent's analysis (1977) suggests that there is evidence for at least two stages of perceptual selection: the early, or global stage, and the later inquiry, or local verification stage. The global or passive stage "packages" information from the environment into different segments, each of which can be attended or rejected. The local stage works with more detailed information from the original packages or segments. This advances the earlier, static feature aggregation approaches to comprise a "figure." According to the global precedence model, global and local features denote separate sets of features (Boer & Keuss, 1982). Thus, global feature availability is not dependent on the accumulation of a sufficient number of local features; on the contrary, the model implies that global feature sampling precedes local feature sampling, or that global feature sampling is faster than local feature sampling. Some predictions from the global precedence model are: (1) it is easier to judge a form on its global characteristics than on its local characteristics, and (2) global characteristics are difficult to ignore, while local ones are easy to ignore. In terms of performance, speed and accuracy are enhanced when the global information is the target of interest.

A number of investigators have worked extensively with the global precedence idea to lend empirical support to the model (McLean, 1979; Navon, 1977, 1981a, 1983; Hoffman, 1980; Martin, 1979; Miller, 1981a, 1981b; Ward, 1983). Most notably, Navon has done exhaustive study with simple shapes and forms to demonstrate the importance of global precedence in perceptual processing. In Navon's view, the task of visual

processing is not just to account for all given outputs, but also to select which part of the surrounding stimulation is worth receiving (1977). The constraints imposed by the optical limits of our eyes and by the nature of our surroundings have implications for visual processing. First, the resolution of most of the stimuli in the immediate visual area is low by default. That is, the crude information extracted from the low resolution parts of the visual field should be "used" for determining which further processing should be done. Second, in a visual environment with many competing stimuli, there is little gain from being "set" for particular types of inputs in normal perception. The visual system should be flexible enough to allow for gross initial cues to suggest the special way for processing any given set of incoming data. This suggests that a "multipass system," in which fine-grained, or local processing, is guided by prior cursory, or global processing, is superior to a system that tries to find a coherent structure for all pieces of data simultaneously. This is in contradiction to the feature models characterized by a parallel processing view, described by such investigators as Gibson (1969), Selfridge (1959), and Treisman and Gelade (1980), because the data gathering in the feature models involves piecing together all stimulus elements into larger "wholes," which would only then be processed further.

Navon has substantiated the simple but powerful global precedence notion with investigations using abstract forms. In one experiment that supports this emphasis, subjects were required to repeat a spoken "H" or "S", and at the same time to press a button when a visual stimulus occurred, without considering what it was. If the visual stimulus was also an H or S, the acoustic reaction was slowed when the spoken and

visual letters were different, speeded up when they were the same. This effect was independent of letter size. The most interesting condition was his use of "compound" letters in which a large letter made up of smaller letters was presented. In a "global-directed" condition, subjects were told to base their responses solely on the large letter; in a "local-directed" condition, they were told to make their decision based on the smaller letters. Navon found that subjects could successfully ignore the small letters in the global-directed condition, responding as rapidly to the large letter whether it was consistent with the smaller letters or not. However, subjects in the local-directed condition could not ignore the large letter, responding faster to the smaller letters when they were the same as the large one. Irrelevant small, or local letters were easily ignored, while global shape was impossible to ignore. Navon argued that this demonstrated the "inevitability of global processing" -- subjects had to process the larger letter first.

The global precedence model has striking similarity to and is related to the interactive channels model of Estes (1972, 1974). In this model, features of stimulus elements are conceived as exciting input channels. Excitation of any input channel exerts inhibitory effects on other channels going to the same or other feature detectors. The more features a "noise" stimulus has in common with the target, the greater the competition for the same input channels as measured by confusability (Eriksen and Eriksen, 1979). The global precedence model appears complementary because it seems to be describing a process just slightly later than the preperceptual stage of concern in the Estes model. Investigations of the global precedence model to this point (Bjork and Murray, 1977) have used the "compound letters" as did Navon.

A number of challenges were immediately presented to Navon's argument of the inevitability of global precedence in immediate perceptual processing. Kinchla and Wolf (1979) suggested that the temporal sequence of events in perceptual processing was not inevitably global-to-local, but that limited ranges of visual angles in Navon's studies were responsible for the results. They suggested that there is an optimal size for forms and that forms of this size (2^{o}) would be processed first, with higher and lower level forms processed subsequently as necessary ("middle-out" processing). This result, though, only supports the previous principle of optimal size precedence related to the work of Larsen and Bundesen (1978), on size scaling. A simple idea that would account for the preferred size (2^{o}) is that the perceptual reference frame always begins at that size, other things being equal. If the frame then had to be adjusted to a certain size in order to detect features of forms that size, it would take longer the farther from optimal was the desired size. All of which simply supports Navon's idea, since very close views of a tree will give no notion that there is a forest to be considered at all.

Further criticism came from Grice, Canham & Boroughs (1983), Hoffman (1980), and Martin (1979), who have raised doubts about the ubiquitious nature of the phenomenon. Their arguments suggest that varying the size of the image, number of local elements, image brightness, task instructions, and other related factors, will create an entirely different visual environment, and fail to produce the global to local sequence. One of the underlying issues emerging from the criticisms is a concern with the artificial nature of Navon's stimuli. Natural and man-made forms have not been examined systematically because

these stimulus populations would require a scaling procedure to specify the nature of the underlying global and local features resic .t in each stimulus item.

Finally, Garner (1983), has argued that many of the experiments on global precedence suffer from a shortcoming that complicates their interpretation: isolated reaction times to the local and global cues either have not been specifically evaluated or, when they have, have frequently not been equated. This difference possibly reflects a greater discriminability of the global cues, which would obviously bias the results in favor of global processing. As noted, both the Miller (1981), and Boer and Keuss (1982), data are interpreted as indicating that global precedence is not a perceptual effect, but a manifestation of a postperceptual process. Both an attentional bias (Miller) and response competition (Boer and Keuss), have been suggested as possible mechanisms for the effect.

More recent rebuttal from Navon (1981b, 1981c, 1983) however, points out that these criticisms concern only to boundary conditions on the phenomenon, which may limit universal applicability, but does not diminish its importance in explaining most immediate perceptual processing under many conditions. Boer and Keuss (1982) contend, in fact, that Kinchla and Wolf have actually replicated Navon's work using a different paradigm, which simply varied the size of the image, and thus adjusted visual angle. This may point up the limitations of the foveal region of the retina, but hardly discounts the global phenomenon. Looking at an image straight on, foveally, will likely not produce global to local stages. However, when foveal fixation is not exercised,

such as during visual search, limited exposure, masking, image degradation, and so forth, then global-to-local stages will occur. By these statements, Navon suggests that global precedence has considerable validity, since things are normally viewed in such a way as to produce it. That is, we typically do not stare at new stimuli "head-on" and analyze them at length, but we search and scan for meaningful information, consistent with other goals.

Further concerns regarding the functional significance of Navon's global precedence concept have continued. Kinchla, Solis-Macias,and Hoffman (1983) stress the need for an "umbrella" concept to explain all perceptual processing using the terms "top-down," "bottom-up," and "middle-out." The idea embraced here is that perceptual processing involves all three, with Navon's work only a case of "top-down." In fact, these investigators insist that all processing begins middle-out, and then may proceed or be guided by bottom-up or top-down approaches (e.g. Rumelhart, 1970). It is clear that although the debate may continue as to precisely where the global precedence concept "fits in" with overall perceptual theorizing, the critical issue here is to determine just how robust the concept is in other circumstances. Extensions of the work would benefit from using a variety of more applied tasks (to allow a wider range of more real world stimuli) to assess its generalizability. An example of such a task is searching for and locating targets on background map displays. This is the basis for the current research.

Hughes, Layton, Baird, and Lester,(1984) have begun this trend of departure from the stimuli typically used to study global precedence (compound letter stimuli). Given the questions raised by critics of

Navon's thesis, the thrust of the newest work is to explore the phenomenon using a wider range of stimulus materials. Hughes, Layton, Baird, and Lester take the approach of studying line segments believed to represent visual features in a very elementary sense: they are expected to be effective stimuli for orientation-selective cells in the visual cortex. Their findings indicate the effect of global precedence for these stimuli is quite robust. The current effott examines the role of global precedence in yet another area - predefined map symbols in everyday use.

CURRENT INVESTIGATION AND HYPOTHESES

The theoretical arguments to this point have been substantiated by studies of abstract images and forms which may have limited generalizability to real world tasks. The current study applies the global precedence perspective to extend Navon's simple construct to more meaningful and complex stimuli. The extent to which global precedence is operative in immediate processing has not been documented with complex stimuli.

The nature of many applied search and location tasks is immediate processing, as opposed to detailed analysis of the same image. Searching for and locating symbols on situation display maps is an example of such a task. The global precedence effect should be an important determinant of the success of target search if in fact two symbols, one target and one non-target (distractor), are in the immediate search area.

Many investigators have shown the impact of distractor elements and background factors in target search (e.g., Eriksen, 1952, 1953, 1955; Eriksen & Schultz, 1979; Eriksen & Eriksen, 1979; McClelland & Miller, 1979; Pomerantz, Sager & Stoever, 1979; Bloomfield, 1972); however, the global precedence concept is a far simpler way to explain the impact of symbol structure on detection, and thus may be more useful in explaining performance in immediate map search tasks. For the current study, a baseline condition establishing the superiority of

detecting the target alone as opposed to having to search for a target in the presence of a distracting symbol, is the first hypothesis:

> Hypothesis 1a: The speed of target symbol identification will be faster for a single target condition than for a target plus distractor condition.

> Hypothesis 1b: The accuracy of target symbol identification will be greater in the single target condition than in the target plus distractor conditions.

Since, according to the global precedence hypothesis, global features are of central importance in certain tasks — especially those of immediate processing -- attempts to process target and distractor symbols which are globally similar should lead to greater task interference than attempts to process symbols which are similar only in local details. Specifically, the current map task requiring immediate search and location of pre-cued targets -- military symbols -- is an example of this type of task. Therefore it is further hypothesized that:

> Hypothesis 2a: The speed of target symbol identification will be affected by the structural relation of a distractor symbol to the target symbol. Speed of target identification will be fastest when the target is from a different global category than the distractor, and slowest when the distractor is from the same global category.

> Hypothesis 2b: The accuracy of target symbol identification will be affected by the structural relation of a distractor symbol to the target symbol. Accuracy of target identification will be greater when the distractor is from a different global category than when the distractor is from the same global category.

The interest in and discriminatory potential of speed and accuracy measures for this type of task follow directly from experimental tasks presented by the investigators mentioned above. In particular, Boer and Keuss (1983) emphasize the importance of these measures for describing

the functions of individuals performing the visual detection and identification tasks under consideration. The current study consisted of two phases:

I. Symbol selection and scaling

II. Symbol detection study

Each phase will be described separately below. Since the results of the phase I scaling portion determined the global symbol structures used as a basis for categorizing symbols for phase II, the analysis and results of phase I will be presented prior to phase II, instead of in a separate analysis and results section. Following the description of both phases, the overall results and discussion will be presented.

I. SYMBOL SELECTION AND SCALING

Selection

Two symbol populations were selected from a large catalog of symbols in current military use (Johnston, Peck, and Landee, 1983). The catalog contains listings of symbols from the three military services as well as other defense agencies. In all, over 1000 military concepts are represented by one or more symbols. Two concepts, having the largest number of symbols, helicopter (19 symbols), and missile (11 symbols), were selected for study. Figure 1 illustrates the helicopter and missile symbol populations used in this study.

Symbol Scaling

The purpose of the scaling analysis was to discover how people categorize the symbols within each of the sets (helicopter, missile) according to global and local features. Multidimensional scaling analysis (MDS) and Hierarchical Clustering Scheme analysis (HCS) were used for this purpose. As was the plan here, other types of tasks - categorization, classification - have been studied using the direct scaling of object similarity relations to predict performance (King, Gruenewald, and Lockhead, 1978).

MDS ANALYSIS

James (1890) considered similarity judgments to be among the fundamental processes of reasoning. Similarity judgments (or, to use the more general term, proximities) between stimuli, are the input data

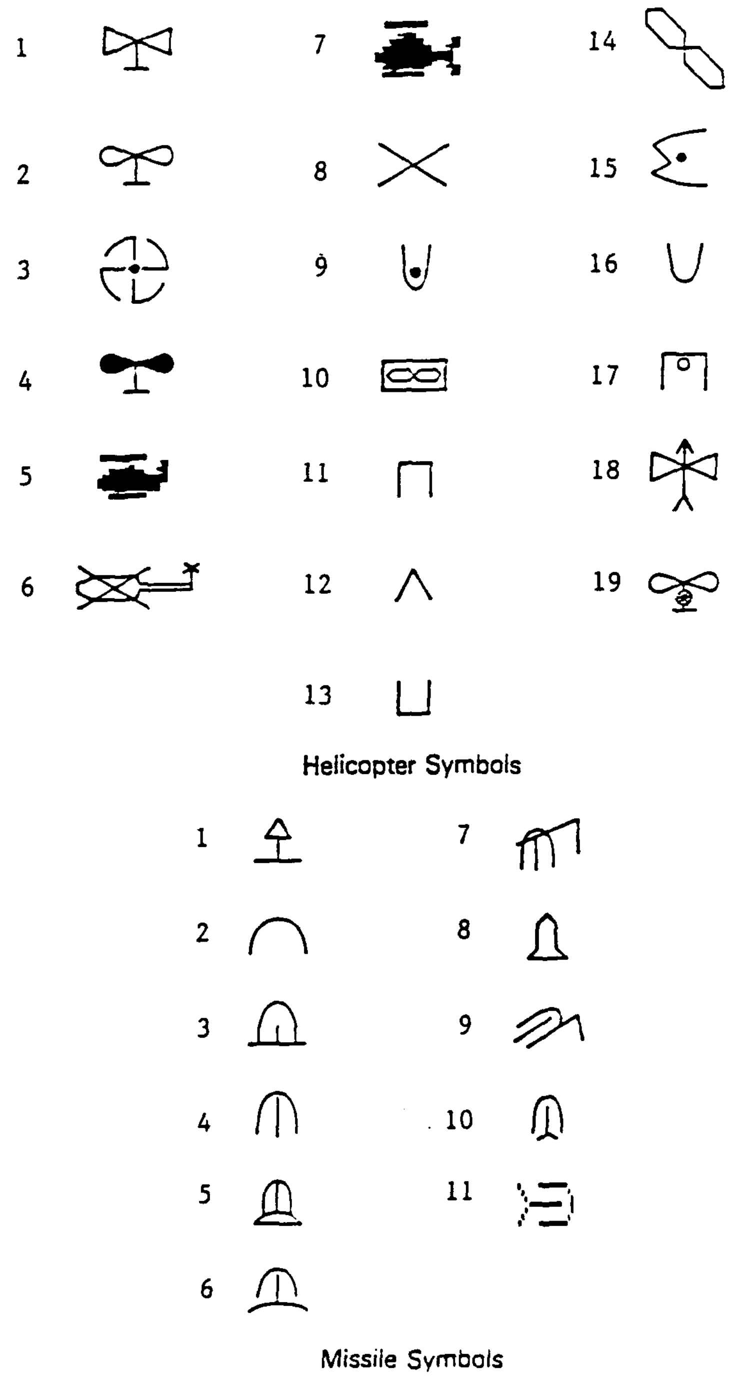


Figure 1. Helicopter and Missile symbols used in the study.

of MDS. Subjects judge these proximities for every paired combination of stimuli. A relationship is presumed to exist between these subjective evaluations and distance as defined and measured on psychological scales or dimensions, (e.g., polar opposites) such as high-low, round-square, small-large, etc. Multidimensional scaling is designed to find the dimensions, given the similarities (Carroll and Wish, 1974). The output of MDS is a spatial representation which consists of a geometric configuration of points (Kruskal and Wish, 1978), where every stimulus item is represented by one of these points. Within this spatial configuration, or map, lies the underlying or hidden structure of the data. Stimuli contain coordinates for every configuration parameter, or dimension. The initial challenge is to determine the appropriate number of parameters or dimensions within the multidimensional configuration relevant to perceptual understanding of the stimuli. The extent to which the data do not fit within a certain number of dimensions is referred to as the stress of that dimensional solution. Stress is a goodness-of-fit measure between the distances within the computer program-generated spatial configuration and the subject-generated proximities. It is the square root of a normalized residual sum of squares of the fit between distances and proximities:

$$\text{Stress} = \left[\frac{\sum_j \sum_k (d_{jk} - \hat{d}_{jk})^2}{\sum_j \sum_k (d_{jk}^2)} \right]^{1/2}$$

where the d's are the distances and the $\hat{d}$'s are the proximities for all stimulus pairs jk (Kruskal, 1964). Stress should decrease as dimensionality increases. The typical procedure for estimating the appropriate number of dimensions, according to Wish and Carroll (1973), is to

calculate MDS solutions for several dimensionalities noting where these stress values begin to "level off." They suggest that if the stress value for a two-dimensional solution is considerably larger than for a three-dimensional solution, but the four-dimensional solution produces a stress value close to that of the three-dimensional, then the preferred configuration would be a three-dimensional solution. In the language of Kruskal and Wish (1978), this is a matter of identifying the "elbow" in a plot of dimensionality versus stress values. One additional rule of thumb these authors offer is that the number of stimuli sets an outer boundary for the possible number of dimensions which can be uncovered. They maintain that there should be at least twice as many stimulus pairs as dimensions, and in cases where the data comprise only a half-matrix of all stimulus pair combinations (minus the diagonal pair of combinations), the number of stimuli minus 1 should be at least four times the number of discovered parameters; or $(I-1) \geq 4R$, where I is the number of stimuli and R is the level of dimensionality.

After determining how many dimensions to use comes the problem of interpreting the dimensions. This entails specifying the psychological meaning of each dimension (Carroll and Wish, 1974). Conceptually, the procedure is to examine what the stimuli at one end of a dimension have in common with each other and what they possess which differs from the stimuli at the opposite end.

A scaling procedure has been developed (Takane, Young and deLeeuw, 1977; Young and Lewyckyj, 1979) which allows nonmetric individual differences MDS. This procedure de-emphasizes the dichotomy of metric and nonmetric measurement levels and proceeds from the assumption that all observations are categorical (Takane, Young, and deLeeuw,

1977). This scaling technique has been named ALSCAL, for Alternating Least Squares SCALing. The ALSCAL method involves an arbitrary dividing of the potential parameter into several subsets. Least square estimates are obtained for one of these subsets while the stipulation is established that all the other subsets are known, constant features of the solution. The estimation is then repeated in an alternating fashion from one subset to another until all subsets have been initially estimated. Iterations of this process proceed until solution convergence occurs (Takane, Young, and deLeeuw, 1977).

Young (1970) feels that his nonmetric multidimensional scaling procedure can allow the user to proceed with data analysis as if the stimulus measurement level were ratio when the number of points is large enough. By large enough, Young suggests approximately 15.

The present study employed the ALSCAL IV MDS program of Young and Lewyckyj (1979), using the 19 helicopter symbols as stimulus points in one analysis, and the 11 missile symbols as stimulus points in a second analysis. The point of both analyses was to discover rather than impose the dimensions used by persons in judging and interpreting the sets of stimuli (Kruskal and Wish, 1978).

Hierarchical Cluster Scheme Analysis

The perceptual judgments obtained in the MDS analysis were further analyzed using Johnson's hierarchical clustering method (1967). The use of this method serves as a further "check" on the dimensions identified in the ALSCAL MDS procedure. Shepard (1972) has argued that this method provides a useful hierarchy to define further the perceptual structure of the MDS analysis. The hierarchy defined in this procedure

uses the same judgment matrices of similarity as the MDS algorithm, but collapsed across individual subjects to form one off-diagonal matrix. The method essentially employs a minimum connectedness procedure based on the computation of a distance function proceeding from the weakest cluster (all symbols form separate clusters) to the strongest cluster (all symbols are in one cluster), by merging symbols in a stepwise algorithm along the way. Conceptually, successive distance measures are combined to form chains, the sizes of which are the largest link distance from individual symbols. The chain distance intuitively measures a kind of connectedness of symbols through the intermediate steps when items are successively linked by the distance measures. The outcome of this analysis is a hierarchically ordered grouping of the symbols ranging from the weakest to the strongest clustering. A computerized version of the hierarchical clustering scheme was used on the helicopter and missile judgment data.(Bell Telephone Laboratories HICLUS program).

Method

Subjects

Twenty subjects were selected to judge symbols according to similarity. These were 16 males and 4 females from an introductory enlisted course at the US Army Intelligence School, Ft. Huachuca, AZ. The range of ages was from 18 to 31, and subjects were screened to insure no prior familiarity with the symbols being used.

Procedure

The twenty participants viewed 226 35mm slides, each of which contained a pair of symbols. The pairs were formulated by pairing all possible combinations of symbols from the helicopter set (171 pairs) and

the missile set (55 pairs). The symbols were randomly paired so that the same symbol was about equally shown on the right or left, and slides were shown in random order, mixing among both sets. For each slide, the task was to indicate, on a five point scale, how similar the two symbols were. Figure 2 illustrates the rating scale used. This scale has been used in numerous studies of this type for similarity judgment (Getty, Swets, Swets, and Green, 1979). Slides were shown for an exposure duration of 3 seconds, followed by an interstimulus interval of 4 seconds for marking the response. The exposure interval was carefully derived from pilot testing to insure that the judgment was based on initial impression only, with no additional opportunity to process the stimuli. Instructions were carefully given to emphasize that the concern of the study was simply to gather information on the similarity of the items at first glance only, and to spend no time or effort trying to "recognize," assign meaningfulness, or utility to the symbols. The sole question at hand was to judge similarity.

The stimulus slides were prepared by drawing with a black pen on a flat, white matte background, and then photographing the images of all possible pairs (random pairs previously derived) using an animation stand. Slides were projected in a classroom setting with standard lighting, and a standard Kodak Carousel projector equipped with a Pi Alphax shutter and ADS timer/counter with shutter driver timing mechanism, that was programmed for the appropriate exposure and response intervals. All subjects were seated approximately 20-30 feet from the large screen, so that visual angle of the symbol images, approximately 2^{o}, was constant. The entire procedure took about 35 minutes.

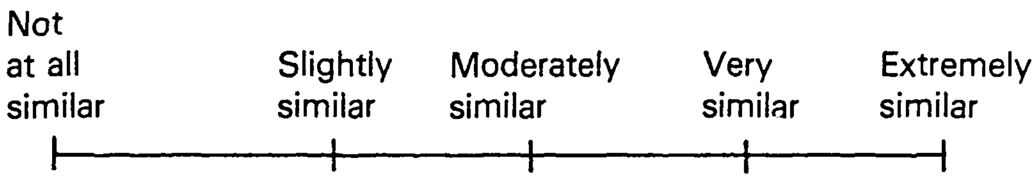


Figure 2. Five-point rating scale used for similarity judgments.

Results

Multidimensional Scaling Analysis

Following data collection, the similarity judgments of the 20 subjects were processsed by the ALSCAL IV program of Young and Lewyckyj (1979). Solutions were derived at several levels of dimensionality so that the stress values of these solutions could be compared and a decision made as to the appropriate dimensionality. Solutions at 2, 3, and 4 dimensions were computed. The stress values of these solutions, are graphed in Figure 3, and it can be seen that the elbow of the plot comes at the stress value of dimension 3 for both the helicopter data and the missile data. Tables 1 and 2 show the values of all stimuli along every dimension for the helicopter and missile symbols. Figures 4 - 9 present plots of the derived stimulus configurations (spaces) for each dimension against every other for both symbol groups.

Hierarchical Cluster Analysis

The similarity data from above was also processed using a computerized version of the Hierarchical Cluster Scheme (HCS) of Johnson (1967). For this analysis the 20 individual data matrices of similarity judgments were collapsed into a group matrix for the helicopter population and one for the missile population. The HCS procedure, as indicated, provides a check on the output from the MDS analysis. Figure 10 presents the HCS output for the 19 helicopter stimuli and Figure 11 for the 11 missile stimuli. The figures are interpreted as follows: the top row indicates the stimulus item number (refer to Figure 1). Each succeeding row, from top to bottom, indicates clusters of stimuli from the weakest possible clustering, where each item is its own cluster,

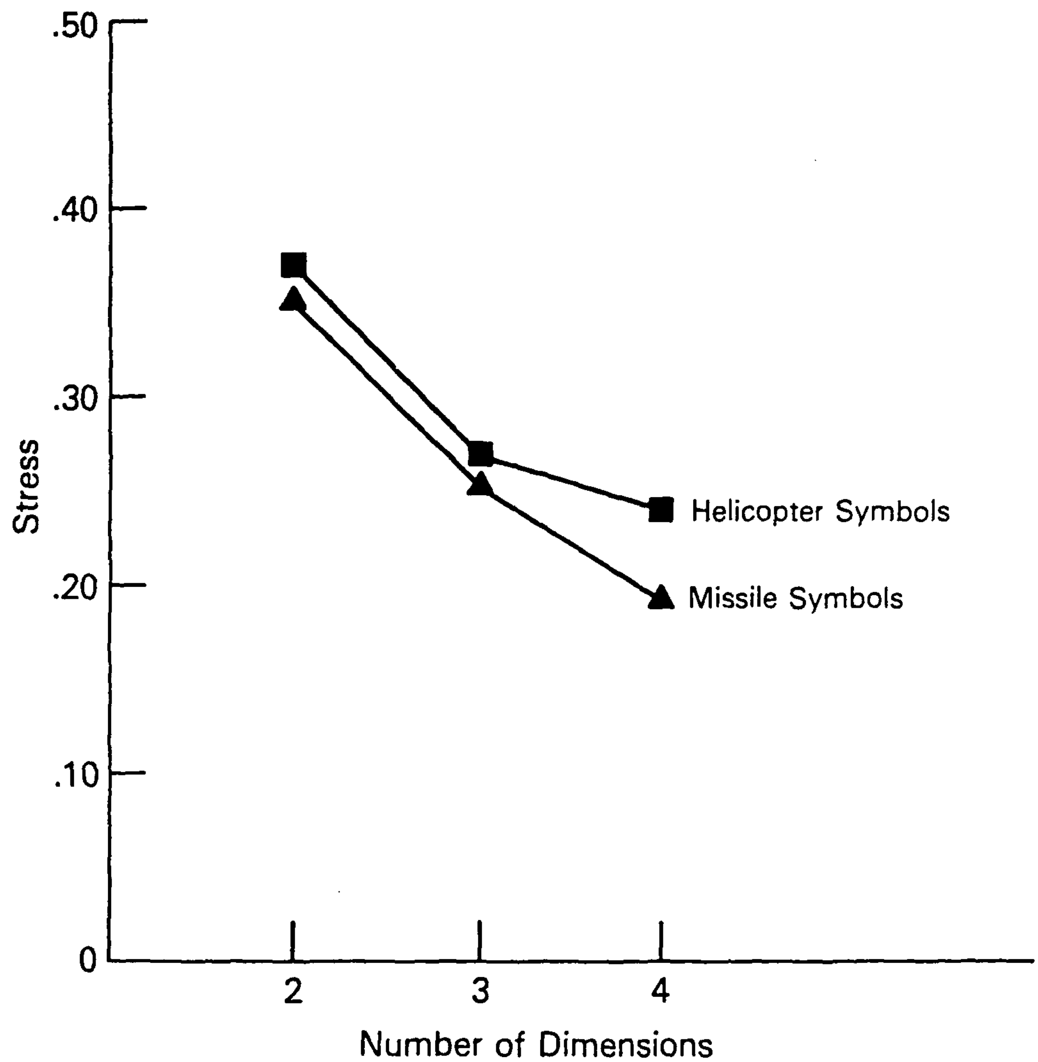


Figure 3. Stress values of MDS solutions over a range of dimensionalities.

DIMENSION

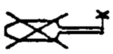
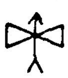
	Symbol	One	Two	Three
1		1.3795	−0.6772	−0.6263
2		1.3396	−0.4079	−0.7781
3		−0.5617	−1.4675	−1.0961
4		1.3456	−0.7795	−0.4244
5		0.5873	−0.0928	1.6542
6		0.6987	0.3629	1.5061
7		0.2527	−0.3731	1.6225
8		0.7876	1.5346	0.2209
9		−1.0934	−1.4568	0.2939
10		0.1273	1.1788	−1.2948
11		−1.5576	0.8571	−0.4648
12		−0.5852	1.2277	1.1898
13		−1.6319	0.6237	−0.4394
14		0.4962	0.5864	−1.5320
15		−0.9027	−1.5300	0.2881
16		−1.0025	−0.8072	1.1517
17		−1.6203	0.4871	−0.6355
18		0.7289	1.4106	−0.0698
19		1.2118	−0.6768	−0.5663

Table 1. Dimension Stimulus Coordinates (Helicopter Symbols)

DIMENSION

	Symbol	One	Two	Three
1		1.9985	0.3907	−0.7635
2		−0.7006	0.1652	−1.6607
3		−0.7559	1.1602	−0.2625
4		−1.1937	0.5590	−0.3690
5		−0.7929	0.8759	0.7548
6		−0.3939	0.4851	1.3565
7		−0.5768	−1.5553	−0.9869
8		1.7104	0.8710	−0.4633
9		−0.1591	−1.7492	−0.0643
10		−0.2806	0.1214	1.3787
11		1.1445	−1.3241	1.0802

Table 2. Dimension Stimulus Coordinates (Missile Symbols)

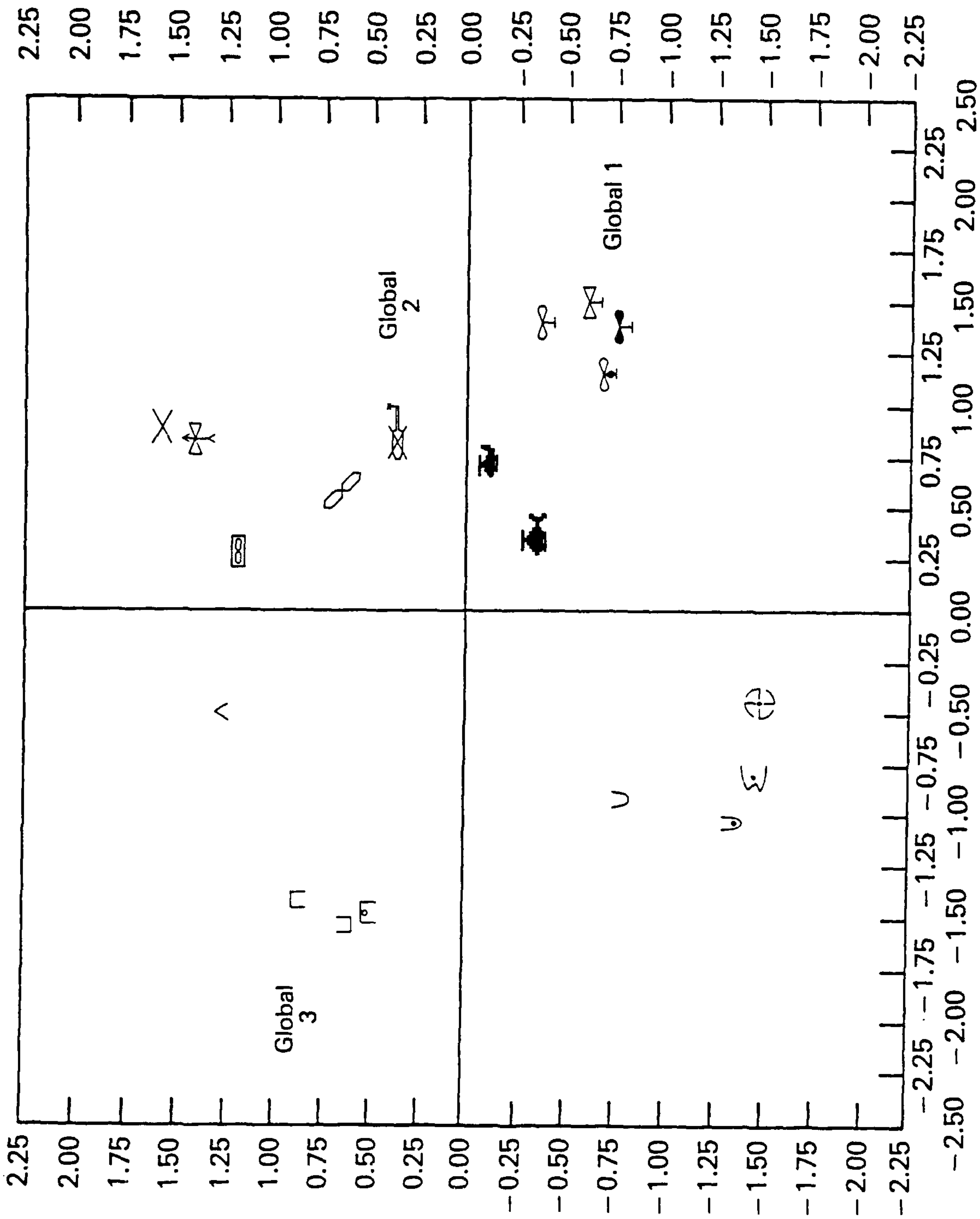


Figure 4. Derived group stimulus space: Dimension One and Two (Helicopter).

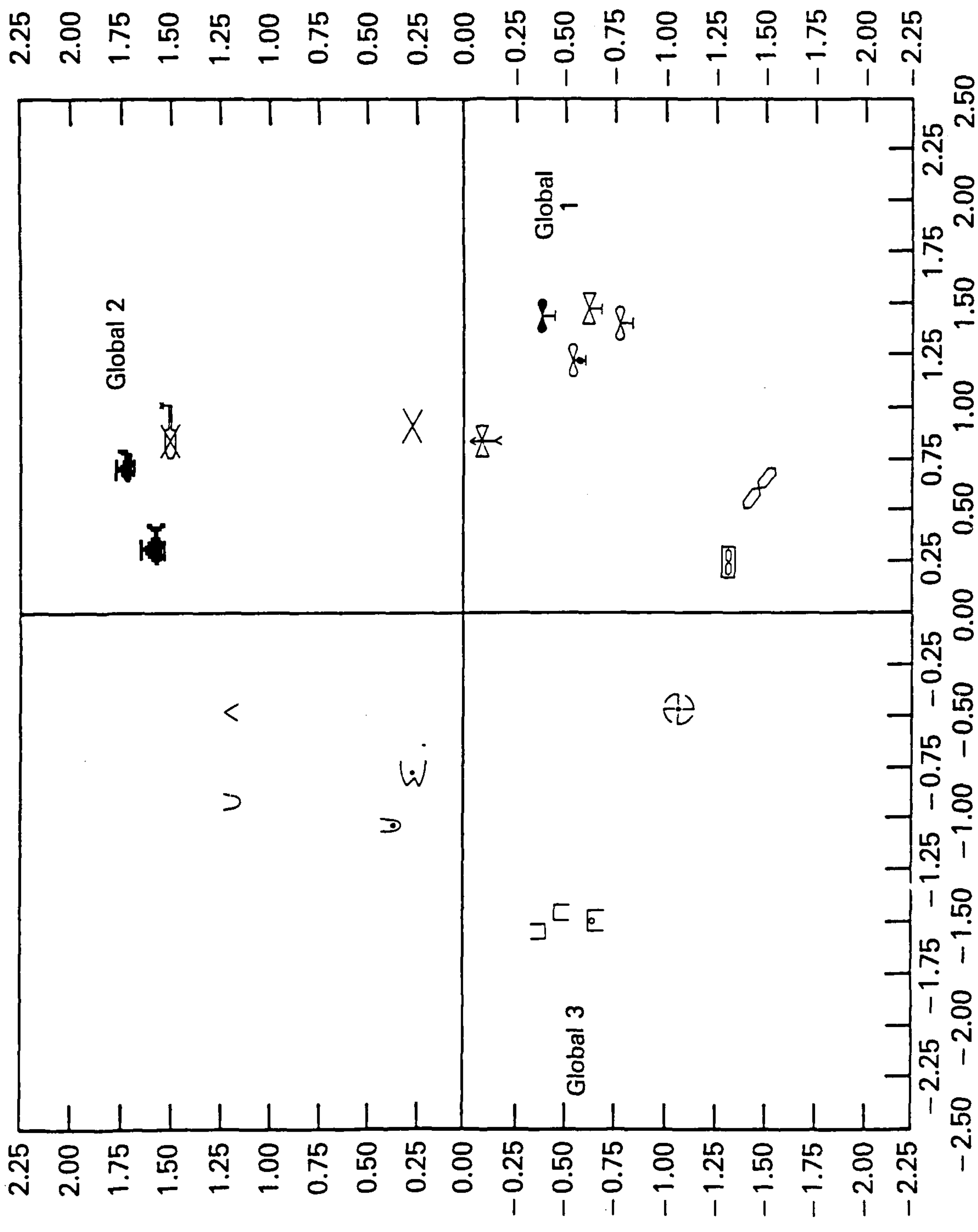


Figure 5. Derived group stimulus space: Dimension One and Three (Helicopter).

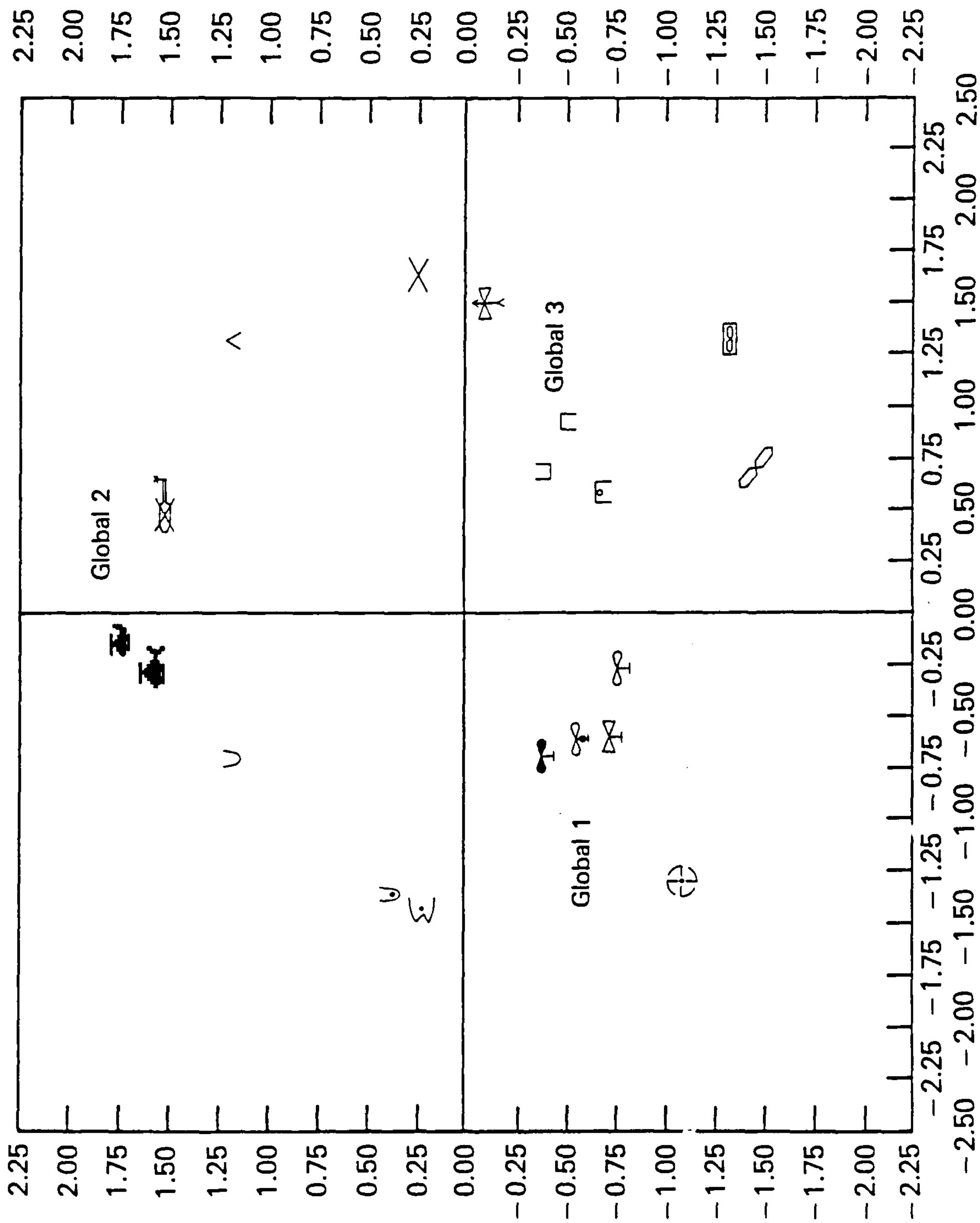


Figure 6. Derived group stimulus space: Dimension Two and Three (Helicopter).

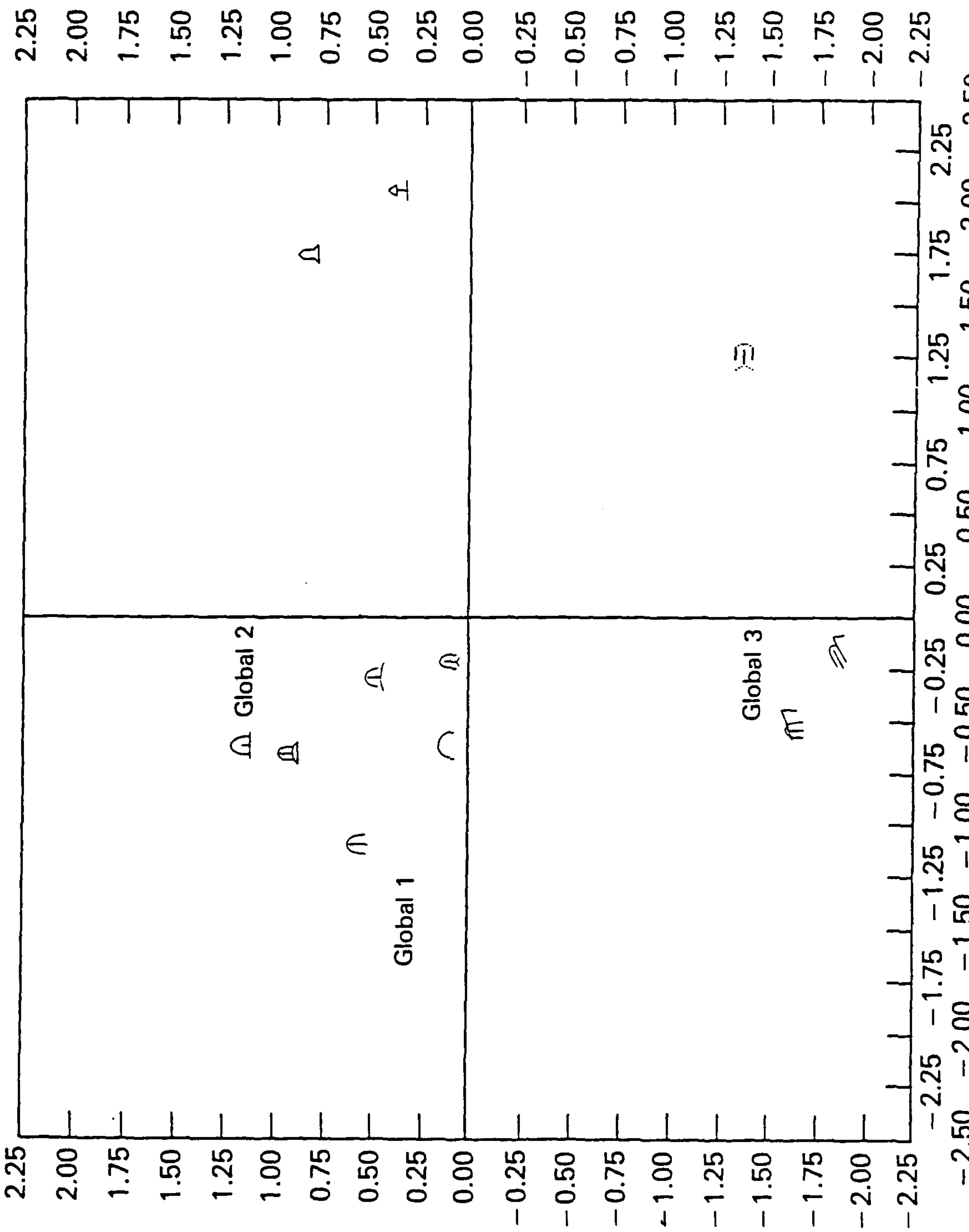


Figure 7. Derived group stimulus space: Dimension One and Two (Missile).

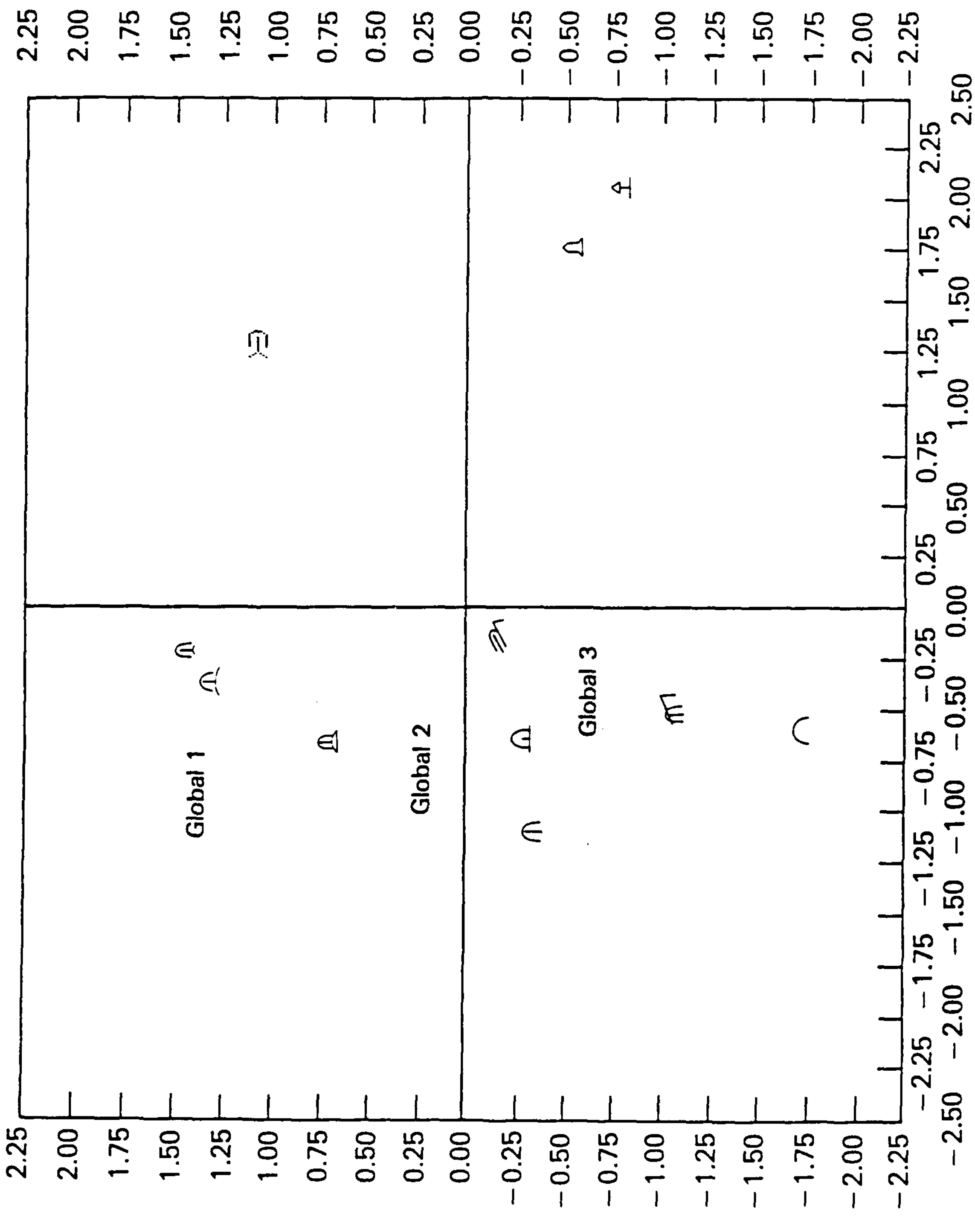


Figure 8. Derived group stimulus space: Dimension One and Three (Missile).

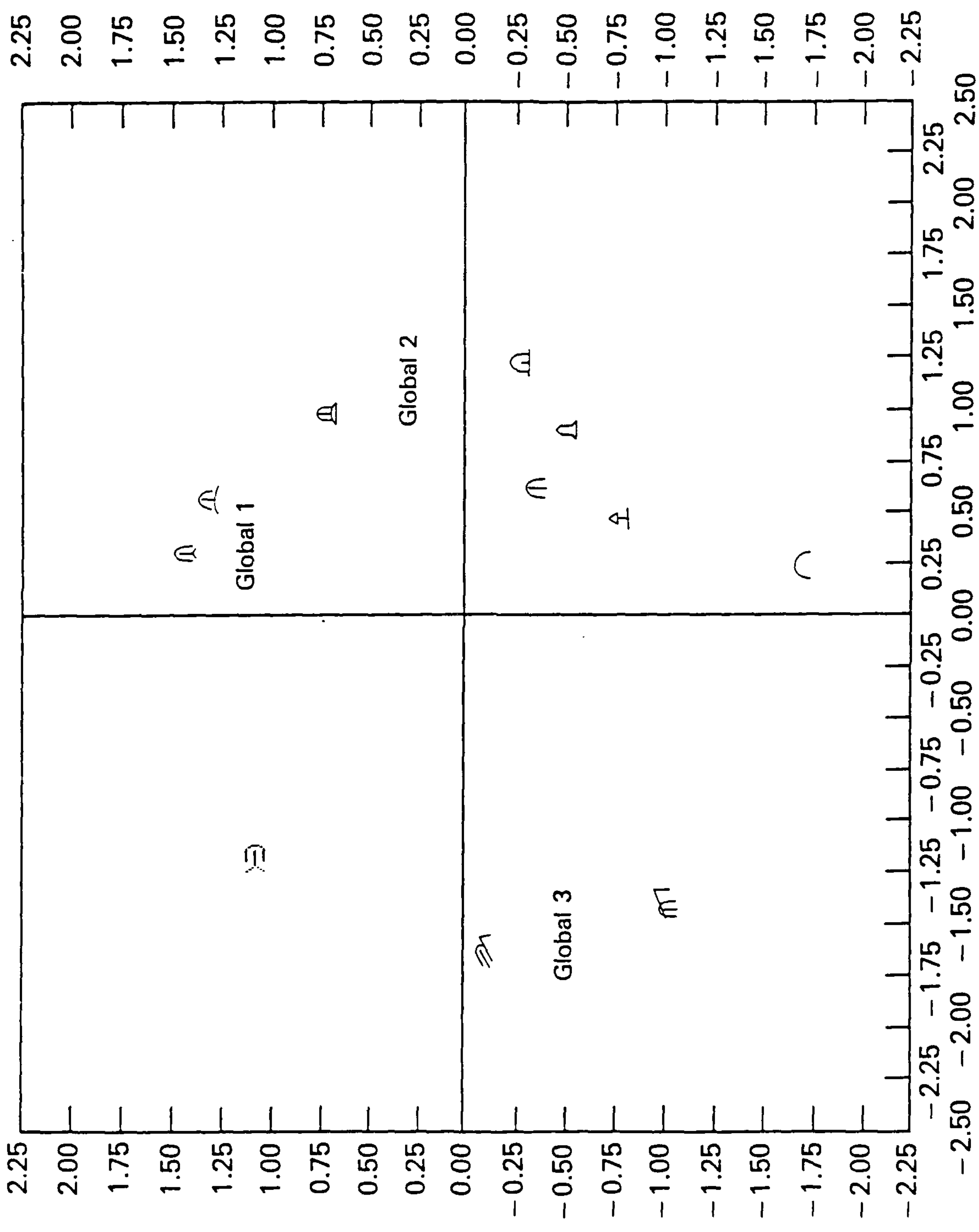
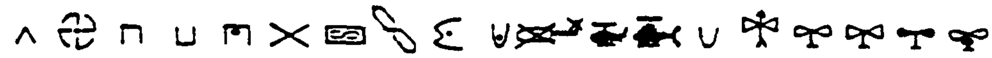


Figure 9. Derived group stimulus space: Dimension Two and Three (Missile).

Connectedness Method



```
                          12 3  11 13 17 8  10 14 15 9  6  5  7  16 18 2  1  4  19
Weak            97.0      .  .  .  .  .  .  .  .  .  .  .  X  X  X  .  .  .  .  .  .
                83.0      .  .  .  .  .  .  .  .  .  .  .  X  X  X  X  X  .  .  .  .  .
                77.0      .  .  .  .  .  .  .  .  .  .  .  XXXXX  .  .  XXX  .
                73.0      .  .  .  .  .  .  .  .  .  .  .  XXXXX  .  XXXXX  .
                69.0      .  .  .  .  .  .  .  .  .  .  .  XXXXX  .  XXXXXXX
                67.0      .  .  .  .  .  .  .  .  .  .  XXXXXXX  .  XXXXXXX
                60.0      .  .  .  .  .  .  .  .  .  XXXXXXXXX  .  XXXXXXX
                59.0      .  .  XXX  .  .  .  .  .  XXXXXXXXX  .  XXXXXXX
"Strength"
   or           58.0      .  .  XXXXX  .  .  .  .  XXXXXXXXX  .  XXXXXXX
"Value"
                47.0      .  .  XXXXX  .  .  .  .  XXXXXXXXX XXXXXXXXX
                45.0      .  .  XXXXX  .  XXX  .  XXXXXXXXX XXXXXXXXX
                43.0      .  .  XXXXX  .  XXX XXXXXXXXXXXXXXXXXXXXX
                40.0      .  .  XXXXX XXXXXXXXXXXXXXXXXXXXXXXXXXX
                38.0      .  .  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                36.0      .  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Strong          34.0      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

End of Method

Figure 10. Hierarchical Clustering Scheme obtained on Helicopter symbols.

Connectedness Method		1		8		7		9		2		3		5		4		6		10		11
Weak	97.0	.		.		.		.		.		.		.		.		X	X	X		.
	65.0	.		.		.		.		.		X	X	X		.		X	X	X		.
	64.0	.		.		.		.		.		X	X	X		X	X	X	X	X		.
	63.0	.		.		.		.		.		X	X	X	X	X	X	X	X	X		.
"Strength" or "Value"	56.0	.		.		.		.		X	X	X	X	X	X	X	X	X	X	X		.
	51.0	.		.		X	X	X		X	X	X	X	X	X	X	X	X	X	X		.
	50.0	.		.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		.
	42.0	.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		.
	39.0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		.
Strong	37.0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

End of Method

Figure 11. Hierarchical Clustering Scheme obtained on Missile Symbols.

signified by a ".", to the strongest clustering at the bottom, where all stimuli are joined into one cluster. It is along the way that "X's" indicate bonding between and then among items before final coherence into one group. For example, for the helicopter stimuli, it is clear that items 5, 7, and 6 are a cluster, items 2, 4, 1 and 19 are a cluster, and that these six in turn are eventually part of a larger cluster. Items 11, 13, and 17 are a separate cluster which merges strongly only as a part of the total, full stimulus set-as-a-whole cluster. Clearly the procedure identifies a hierarchy of clusters and sub-clusters based on the distance metric.

Naming of Stimulus Clusters for Global and Local Features

Having determined the multidimensional scaling and hierarchical clustering solutions, the next task was to match up the revealed clusters with global and local descriptors. Although not in total agreement, the two analyses provide nearly the same recognizable clusters. The HCS solution provides large clusters which branch to smaller sub-clusters, and the MDS portrayal by dimensional plots provides a means of naming global groups and suggests certain local features. Figures 12 and 13 show the HCS analysis embedded in a three-dimensional portrayal of the MDS solutions for the helicopter and the missile stimuli. The three dimensions are named according to the salient features of the identified clusters. For example, in the combined helicopter plot of Figure 12, dimension one is vertical vs. horizontal orientation, the salient feature being overall orientation. Dimension two is rounded/ smooth vs open/square. A final dimension is simplicity vs complexity.

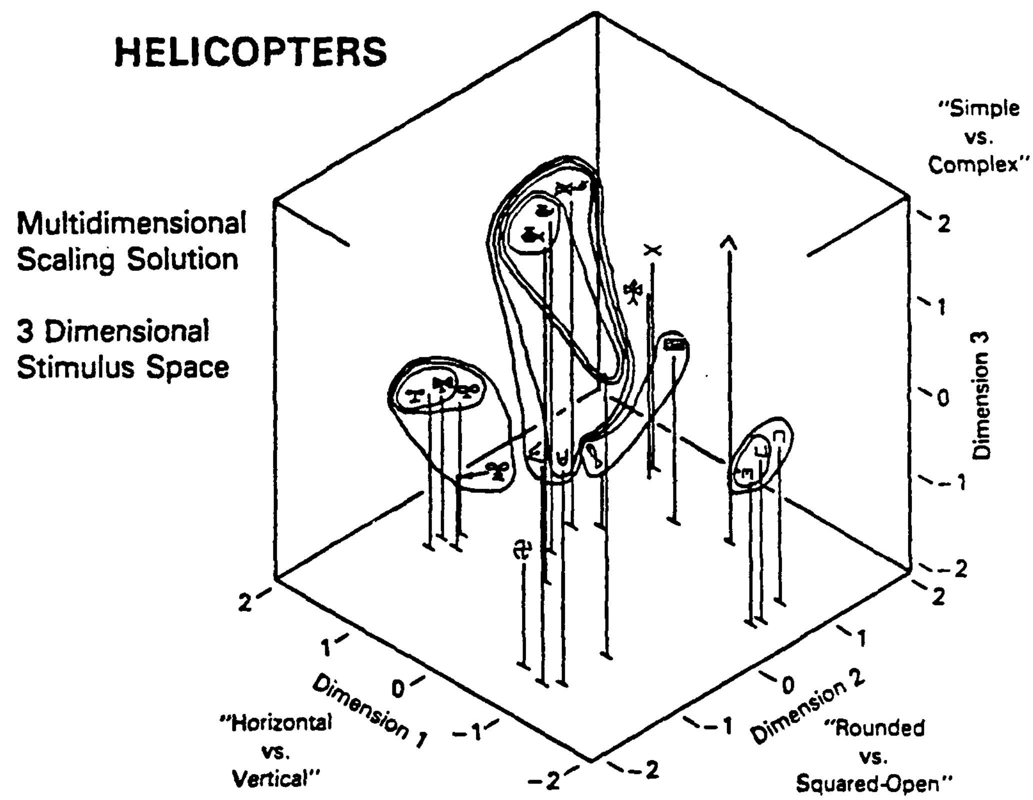


Figure 12. Hierarchical Clustering Analysis embedded in three-dimensional MDS scaling solution for Helicopter symbols.

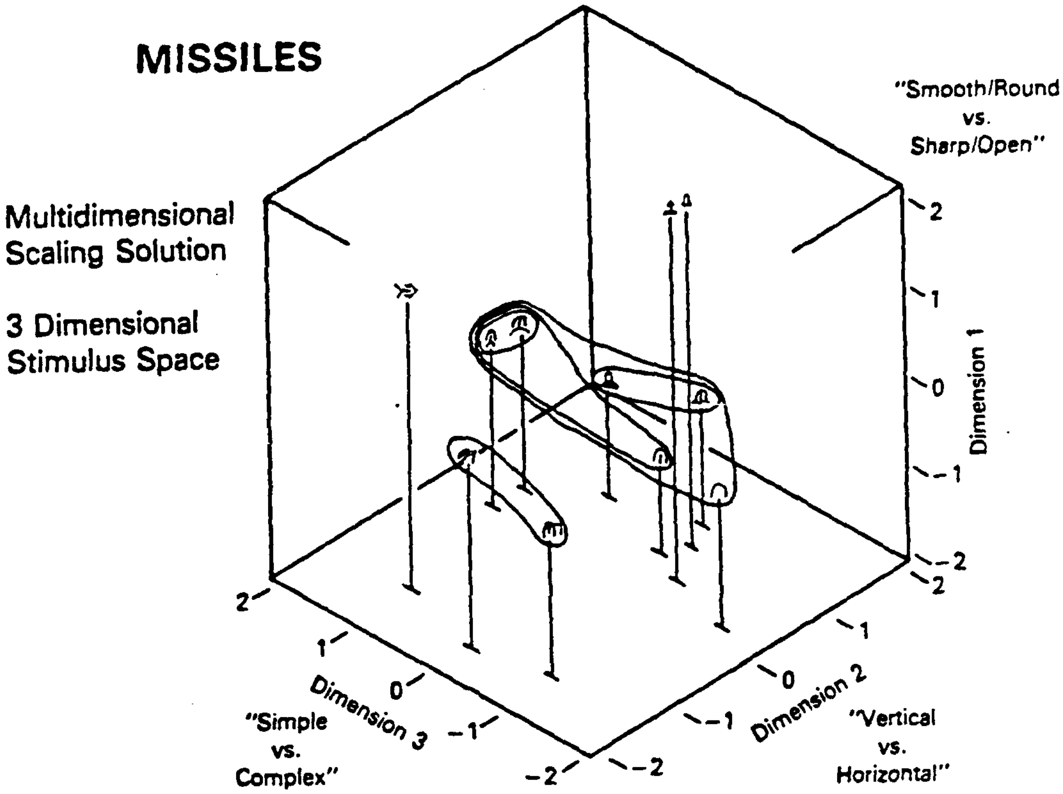


Figure 13. Hierarchical Clustering Analysis embedded in three-dimensional MDS scaling solution for Helicopter symbols.

These same rough categorizations apply equally well to the missile population. There are further distinctions relating to filled vs. unfilled, two-part figure vs. one part figure, but these provide more specification than is required to capture the global structural relations described by the orientation and rounded/smooth descriptors.

The method of categorizing the identities of the stimulus clusters was via visual inspection of the MDS and HCS plots. The simplistic nature of the forms was straightforward enough to justify this introspective approach, which is the method of choice for most analyses (Takane, Young, and Lewyckyj, 1977). The clusters shown both by MDS dimensional plots and the HCS output diagrams capture 3 global clusters for both the helicopter and missile stimuli, and within these, one or two local levels.

For the helicopter stimuli, global cluster 1 (horizontal, rounded, open) consists of items [2, 1, 4, 19]. Global cluster 2 contains items [9, 6, 5, 7, 16], (horizontal, closed), and global cluster 3, items [13, 11, 17] (vertical, square, open). Global clusters 1 and 2 are closer perceptually than clusters 1 and 3 or 2 and 3. Also, within each global cluster, there are further subclusters which correspond to local element definition. For example, cluster 1 contains items [1, 4] which are most closely matched for both global and local features. According to the hypotheses presented previously, it would be expected that the most interference in target detection would occur if item 1 were paired with item 4. This is because processing must proceed through two initial global levels to a local level before a distinction can be made. This would be less so if the two items were from global 1 and global 2, although there would be interference, and the very least

interference between global 1 and global 3, or global 2 and global 3. Within global 3, however, again a great deal of interference would be expected between items [11, 13], and to a lesser degree [17] with [11] or [13]. Items not clearly fitting into the three identified clusters, standing "alone" as it were, are clearly from another type of global population of which these are the sole representative. Referring back to the named stimulus dimensions of the MDS plots, other types of symbols in these sets could be devised. The hypothesized impact of the stand alone symbols on the items in global sets 1, 2, and 3 already identified would be minimal.

To summarize, for the helicopter items, three distinct clusters are identifiable from both the MDS and HCS plots. The HCS structure shows successive aggregation of items into two larger global clusters [G1, G2], and [G3]. The MDS plots show dimensional comparisons which allow the assignment of names (horizontal structure/vertical structure, rounded/smooth structure, filled vs. unfilled, simple vs complex structure) to visually identify features which account for the global and local clustering.

The missile stimuli follow a course similar to the helicopter items. Global category 1 consists of items [4, 6, 10] (vertical, open); global 2 [3, 5] (vertical, closed); and global 3 [7, 9] (horizontal, open). Global 1 and 2 are subsets perceptually closer to each other than global 3, just as in the helicopter population. The same reasoning applies to the impact of any given item named as distractor on an item named as target. Items [6] and [10] will interfere most with each other, just as will [3] with [5], and [7] with [9]. Greater interference will occur in match-ups of global 1 items with global 2, than with

global 1 and 3 or global 2 and 3. Stimulus items not clearly in any of the 3 global categories, [8], [1], [11], will also present minimal or no interference in target identification. These identified structures are precisely what is required to examine detection performance in a target search task. This is the basis of Phase II: Symbol detection study.

II. SYMBOL DETECTION STUDY

Introduction

The identified symbol structures of Phase I form the basis of treatment combinations to examine in a detection paradigm. A symbol detection study was conceived to offer a realistic simulation of the use of the stimulus symbols. A common military task performed with symbols of this type (helicopter, missile) is simply immediate search for and location of a target upon request. These symbols are typically overlaid on a map background sector which is unchanging; that is, an individual quickly accomodates the map features (roads, terrain lines, rivers, grid squares, etc.) and becomes concerned with the overlay of images against this background to portray events or describe a situation. The identification of a target symbol is the recognition of such an event.

Method

Subjects

Subjects were 5 males and 11 females, ranging in age from 19 to 45, and selected from the local community. All had 20-20 normal or corrected vision. All subjects saw all stimulus pair conditions.

Setting and Apparatus

A simplified version of this symbol search and locate task was devised using a computer generated map display typical of those in use or projected for use in this application (See Figure 14 for a photograph of the digitized map display). The computer used to generate the

Figure 14. Photograph of computer generated map display for Phase II Symbol Detection Study.

displays and manage the stimulus presentation was a VAX 11/780 mainframe driving a Sanders 1024X1024 high resolution color graphics system. Symbols were generated using Fortran subroutines executable to permit drawing with a data tablet. The hardware and software allowed selected target and distractor symbols overlaid onto a map display to be presented as "slides" for a specified exposure duration.

Stimuli

The stimulus "slides" used in this task consisted of 127 map displays containing either one target symbol or one target symbol plus one distractor symbol. The total of 127 trials was determined by selection of candidate symbols from both the helicopter and missile sets which were representative of the global clusters identified in Phase I scaling analyses.

For the helicopter items, 12 symbols were selected, as shown in Table 3. Items [3], [10], and [12] were selected as representative of symbols from different global clusters to contrast with the 3 key clusters identified above. Of these 12 symbols (from global clusters 1-3 and the additional miscellaneous distractors) all possible pairs of symbols yield a total of 66 trials (n(n-1)/2). A total of 82 helicopter stimulus trials were produced by adding 16 trials of the "target alone" condition (25% of 66).

For the missile items, a similar selection procedure was used, with a total of 9 items, shown in Table 4. Items [8] and [1] were selected as representative miscellaneous distractors. All possible pairs using n=9 yields 36 trials, and an additional 9 target alone trials (25% of 36), provides a total of 45 missile slides.

Table 3.

Identified Global Clusters from Scaling Analyses with Selected Helicopter Symbols.

Global cluster 1:	(1, 4, 2)
Global cluster 2:	(5, 7, 6)
Global cluster 3:	(11, 13, 17)

Table 4.

Identified Global Clusters from Scaling Analyses with Selected Missile Symbols.

Global cluster 1:	(6, 4, 10)
Global cluster 2:	(3, 5)
Global cluster 3:	(7, 9)

Combining the 82 helicopter trials with the 45 missile trials yields the total 127 subject trials. Each slide was constructed by placing either one or two symbols on the map background. This was done by dividing the map into four equal quadrant areas, then into two circular zones extending 1" and 3" (approximately 4.77° to 14.25° visual angle area) in radius from screen center. Figure 15 presents a schematic drawing of the quadrants and placement zones. The zones were derived from similar studies to maintain subject search within a confined area while still providing a parafoveal search region. Symbols were placed in separate quadrants to allow a selection mechanism for subject response. A target was never in the same quadrant as a distractor. The placement of targets and distractors for each slide was accomplished by randomizing 1) quadrant, 2) placement zone, 3) which item of a given pair would be target and which would be distractor. The overall stimulus trial set of 127 items was then randomized. This for any given trial a subject might see a target alone, a target-distractor missile pair, or a target-distractor helicopter pair.

Symbol Size and Viewing Conditions. Particular attention was paid to symbol size selection and subject viewing distance since visual angle has been indicated as an important factor in the elicitation of the global precedence effect. General agreement exists that images subtending a 2° visual angle are optimal for this purpose. The 2° selection is supported by a summation of arguments by Ward (1982), who reconciles the dispute between Navon (1977) and Kinchla and Wolf (1979) by suggesting a principle of optimal size precedence. Features of forms nearest this size will be detected first in a search paradigm; and the farther from

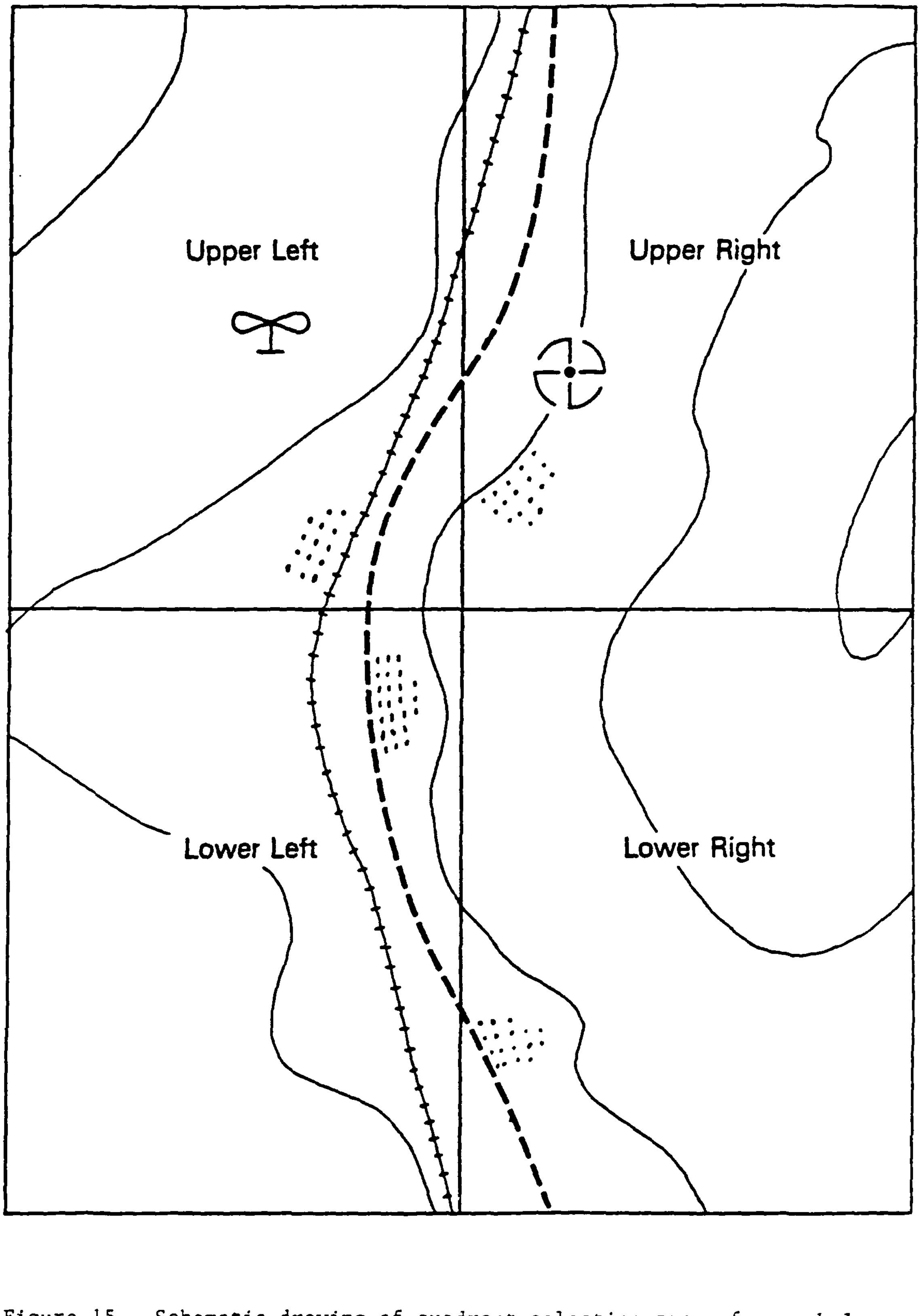


Figure 15. Schematic drawing of quadrant selection zones for symbol targets on the map display.

the optimal size the form is (larger or smaller) the slower will be detection of the larger form or its features. Actual symbol size for this study was 1.27cm, with a subject viewing distance of 60cm. This provided the desired visual angle of 2°.

Symbol Color. Symbol color was a medium blue - full intensity for pure blue and green bits on the Sanders Graphic system (Sanders "aqua") - because this color normally is used for this type of military (Blue "Friendly" Forces) application. Since all stimulus symbols were of the same color, with an invariant background, this was not considered an additional variable.

Procedure

Subjects were instructed to indicate the location of the target symbol by pressing one of four function keys on a keyboard corresponding to four "quadrants" on the screen: upper left, upper right, lower left, and lower right. The instructions (see Appendix for text) illustrated the four quadrants and provided a session of three practice trials which could be repeated until the subject expressed familiarity with (confidence in) the procedure. Following this the experimental procedure began, presenting each of the 127 trials, using the following sequence for each trial:

- Target alone
- Map display with one or two symbols for 0.8 seconds
- Subject response (latency recorded from time of initial map display to key press)

The 127 trials were presented in two blocks (one of 65 trials and one of 62 trials) to allow for a short break. Half the subjects saw block one followed by block two, and the other half of the subjects saw block two followed by block one, to counterbalance for any practice and learning effects which might have occurred. Each subject was tested individually which took about 15 - 20 minutes. Following a session, subjects were thanked and dismissed.

Design

Each subject served as their own control for all stimulus conditions. The design consisted of a repeated measures analysis of variance for response latency and correctness of quadrant selection for each trial. Further, the stimulus items for the helicopter and missile populations were broken out into two separate analyses. Reflecting the experimental hypotheses, the conditions for analysis were:

(1) Detection of target alone will be significantly faster and more accurate than detection of target with distractor

Target + Distractor	Target alone
102 trials	25 trials

(2) Speed and accuracy of target detection will be affected by the presence of distractor symbols from similar global and global-to-local structural categories. The more globally and locally similar a distractor is to a target, the slower and less accurate will be target detection.

For the global categories and subcategories selected for the missile and helicopter stimuli, four levels of interference were considered:

1. M:Most interference - symbols globally and locally similar
   3 helicopter pairs and 3 missile pairs

2. 2M:2nd most interference - symbols globally similar, locally dissimilar
6 helicopter pairs, 2 missile pairs

3. 3M:3rd most interference - symbols from close global clusters
9 helicopter pairs, 6 missile pairs

4. L: Least interference - symbols from distant global clusters
48 helicopter pairs, 25 missile pairs

Results

The data from the 16 subjects were analyzed using a 5-way ANOVA repeated measures design as detailed in Winer (1971). Four separate analyses were performed, two for the helicopter items (response latency and accuracy), and two for the missile items (response latency and accuracy). Mean reaction times (transformed to logarithms to normalize the distribution) and mean proportion correct target selection were used for analysis. Since the number of cell entries for the interference levels described above was unequal, there may be some concern regarding mean reliabilities. However, for each trial mean (target alone or target-distractor pair) it will be recalled that 16 responses were obtained. This repeated measures situation insures very high reliability even in conditions containing only three target-distractor pairs (e.g., M condition), since in all cases, all subjects saw all stimuli. Also, heterogeneity of variances between conditions was examined using a variation of Hartley's F max test (Winer, 1971). In no cases were the variances indicative of violation of the homogeneity of variance constraint. Tables 5-8 present summaries of the ANOVA result.

Table 5.

ANOVA Summary - Response Latencies, Helicopter Symbols

Source	df	MS	F
Target-Distractor Interference	4	.01679	4.67 *
Error	60	.00359	

*p < .005

Table 6.

ANOVA Summary - Response Latencies, Missile Symbols

Source	df	MS	F
Target-Distractor Interference	4	.02014	5.35 *
Error	60	.00377	

* $p < .001$

Table 7.

ANOVA Summary - Response Accuracy, Helicopter Symbols

Source	df	MS	F
Target-Distractor Interference	4	.06049	2.15 ns
Error	60	.02807	

Table 8.

ANOVA Summary - Response Accuracy, Missile Symbols

Source	df	MS	F
Target-Distractor Interference	4	.11668	4.37 *
Error	60	.02673	

* $p < .005$

Following the ANOVA, planned comparisons between specific means were conducted, using Duncan's Multiple Range test as detailed in Pedhazur (1980), and Convey, (1980). The contrasts of interest correspond to comparisons among the different global pairings to reveal the impact of distractor items on target items, as well as the contrast between the target-distractor pairs and target-alone condition (Tables 9 and 10).

Helicopter Symbols - Latency Data

An F ratio (F= 4.67) from the one-way ANOVA performed on the helicopter symbol response latencies was found to be significant (p=<.005). The planned comparisons tested with the Duncan's Multiple Range test yielded t-ratios indicating mixed support for the impact of the target-distractor conditions. The predicted differences were, first, the target alone condition would be faster than target-distractor conditions, and this can be seen in contrast one (Table 9). Among the symbol pair conditions, the predicted interference was to be greatest (produce the slowest latencies) where symbols from within global categories were paired with one another (conditions M and 2M). Following this, closer global categories were projected to interfere more when representative symbols were paired (condition 3M), and least when distractors were from distant global categories, especially "stand alone" distractors (condition L). Mixed support is provided for the hypothesis in this situation, as can be seen by the contrasts between the various categories of symbol pairs. In the condition with most interference, where globally and locally similar symbols were paired, the response times clearly are longer (contrasts 2, 6, 7, 8), but not significantly

Table 9.

Planned Contrasts between Mean Response Latencies Using Duncan's Multiple Range Test, Helicopter Symbols ($\alpha = .05$).

Description		Mean Response Latencies (logrithms)
Control Condition (C)		.12484
Target-Distractor Conditions (TD)		.17990
Individual Target-Distractor Conditions		
Most distracting (globally + locally similar)	(M)	.20715
Second most distracting (same global category)	(2M)	.15274
Third most distracting (close global categories)	(3M)	.19192
Least distracting (distant global categories)	(L)	.16781

Contrast			Critical Value	
1.	C-TD	= .05506	.04237	significant
2.	M-C	= .08231	.04708	significant
3.	2M-C	= .02790	.04237	n.s.
4.	3M-C	= .06788	.04603	significant
5.	L-C	= .04297	.04458	n.s.
6.	M-2M	= .05441	.04603	significant
7.	M-3M	= .01523	.04237	n.s.
8.	M-L	= .03934	.04458	n.s.
9.	2M-3M	= .03917	.04458	n.s.
10.	2-L	= .01507	.04237	n.s.
11.	3M-L	= .02411	.04237	n.s.

longer in all cases. Similarly, with the next most interference, (globally similar/locally dissimilar pairs), the contrast between this and the most interfering and lesser interfering conditions shows only a significant difference between the first and second categories (contrast 6). Remaining categories (contrasts 7-10), do not discriminate significantly among themselves. Although the most distracting category emerges as requiring the most processing time, the other categories are slightly out of order, proceeding from most to least.

Missile Symbols - Latency Data

An F ratio ($F = 5.35$) from the one-way ANOVA perfomed on the missile response latencies was found to be significant ($p < .001$). Planned contrasts between specific means, using Duncan's Multiple Range Test, are shown in Table 10. Findings are very similar to those from the helicopter population, although individual contrasts in the target-distractor conditions are a little better differentiated. The control (target alone) condition is significantly different from target-distractor conditions (contrast 1). Also, all target-distractor conditions singularly support this except in the least distracting category (contrasts 2-5). As in the helicopter data, the categories of distraction do not proceed neatly in order from most to least (contrasts 6-11), although their order is different here than for the helicopter symbols. In general, for both the helicopter and missile populations, support is provided for the original hypotheses related to response latency, although hypothesis 2a is supported more by overall trend than by significant mean differences.

Table 10.

Planned Contrasts between Mean Response Latencies Using Duncan's Multiple Range Test, Missile Symbols ($\alpha = .05$).

Description		Mean Response Latencies (Logs)
Control Condition (C)		.13649
Target-Distractor Conditions (TD)		.19332
Individual Target-Distractor Conditions		
Most Distracting (globally + locally similar)	(M)	.19196
Second most distracting (same global category)	(2M)	.23068
Third most distracting (close global category)	(3M)	.18968
Least distracting (distant global categories)	(L)	.16101

Contrast			Critical Value	
1.	C-TD	= .05683	.03819	significant
2.	M-C	= .05547	.04148	significant
3.	2M-C	= .09416	.04825	significant
4.	3M-C	= .05319	.04017	significant
5.	L-C	= .02452	.03819	n.s.
6.	M-2M	= .03869	.03819	significant
7.	M-3M	= .00228	.03819	n.s.
8.	M-L	= .03095	.04017	n.s.
9.	2M-3M	= .04097	.04017	significant
10.	2M-L	= .06964	.04148	significant
11.	3M-L	= .02867	.03819	n.s.

Helicopter Symbols - Accuracy Data

An F ratio from the one-way ANOVA ($F=2.15$) on the proportion of correct helicopter targets selected, by distractor category, was found to be not significant. During pilot study for this detection experiment, it was resolved that a .8 second presentation was optimal for subjects to allow search and location of the targeted symbol. It is clear that, for these accuracy data, hypotheses 1b and 2b are not supported. The reason for maintaining the long presentation time was to provide the needed opportunity to search the display. It appears that this also allowed for a ceiling effect because, in most cases, subjects were able to select the correct symbol as target. Table 11 shows contrasts among the proportions correct. Although these are not significant, the trend toward increased errors in the distractor conditions is apparent, especially in the most distracting condition matched with the target-alone condition (contrast 2).

Missile Symbols - Accuracy Data

An F ratio obtained from the one-way ANOVA ($F=4.37$) on the proportion of correct missile targets selected, was found to be significant ($p < .005$). In this case, hypothesis 1b is supported (difference in accuracy between target-alone and target-distractor conditions); hypothesis 2b (discrimination between specific target-distractor conditions) is not supported. Table 12 shows the contrast means for these findings. Contrast 1 (control vs target-distractor) is significant, as are all individual target-distractor categories vs control (contrasts 2-5). The within target-distractor conditions do not provide significant differences (contrasts 6-11). Although the trend is toward fewer

Table 11.

Planned Contrasts between Mean Response Accuracies (Proportion Correct) Using Duncan's Multiple Range Test, Helicopter Symbols, ($\alpha = .05$).

Description		Mean proportion correct
Control condition (C)		.96
Target-Distractor Conditions (TD)		.86
Individual Target-Distractor Conditions		
Most distracting (globally + locally similar)	(M)	.83
Second most distracting (same global category)	(2M)	.85
Third most distracting (close global categories)	(3M)	.88
Least distracting (distant global categories)	(L)	.90

Contrast			Critical Value	
1.	C-TD	= .10	.118	n.s.
2.	M-C	= .13	.131	n.s.
3.	2M-C	= .10	.128	n.s.
4.	3M-C	= .08	.124	n.s.
5.	L-C	= .05	.118	n.s.
6.	M-2M	= .02	.118	n.s.
7.	M-3M	= .05	.124	n.s.
8.	M-L	= .07	.128	n.s.
9.	2M-3M	= .02	.118	n.s.
10.	2M-L	= .05	.124	n.s.
11.	3M-L	= .02	.118	n.s.

Table 12.

Planned Contrasts between Mean Response Accuracies (Proportion Correct) Using Duncan's Multiple Range Test, Missile Symbols, (α=.05).

Description		Mean proportion correct
Control Condition (C)		.96
Target-Distractor Conditions (TD)		.79
Individual Target-Distractor Conditions		
Most distracting (globally + locally similar)	(M)	.83
Second most distracting (same global category)	(2M)	.71
Third most distracting (close global categories)	(3M)	.80
Lease distracting (distant global categories)	(L)	.82

Contrast		Critical Value	
1. C-TD	= .17	.115	significant
2. M-C	= .13	.115	significant
3. 2M-C	= .25	.128	significant
4. 3M-C	= .16	.125	significant
5. L-C	= .14	.122	significant
6. M-2M	= .12	.125	n.s.
7. M-3M	= .03	.122	n.s.
8. M-L	= .01	.115	n.s.
9. 2M-3M	= .09	.115	n.s.
10. 2M-L	= .11	.122	n.s.
11. 3M-L	= .02	.115	n.s.

correct in the more distracting conditions, overall the mean differences do not represent discretely significant steps.

Discussion

A number of conclusions may be drawn from the response latency and accuracy data presented above. First, there is a trend toward faster response time and greater accuracy in detecting a target alone than in selecting a target in the presence of a distractor. Second, the accuracy measure provides only a picture of the trend of factors important to the performance rather than a precise discrimination between interference conditions. Third, although response latency is an important discriminator of interference conditions among target-distractor pairs, there is considerable variability in the mean scores, some of which are very rapid, similar to the target alone condition, and others which are clearly from different populations. Fourth, the missile population of symbols was better in terms of definition of global categories which determined the performance in the detection study.

In earlier discussions about Navon's studies (1977, 1981a, 1981b, 1981c), using compound letter stimuli, it was stated that these stimuli were very carefully constructed to precisely capture global as well as local features, in an almost artificial way. In the present study, an existing database of symbols was examined in order to derive the global and local features. The scaling procedures used (MDS and HCS) seem to provide clarity in defining global features, but fail to provide explication of local features. In the studies using artificial representations, the task typically involves very short (less than .1 second) exposures and no demand for target search. For the current study,

exposure time was increased to allow for search, since the image was always in a slightly different position, and to allow for recognition of location (quadrant of map display) as a component of the response. Given this additional processing time made available, it is likely that subjects were able to proceed, in many cases, beyond the initial global analysis, and on to local differentiations. This would explain not only the ceiling effect for response accuracy, but suggests that a more detailed understanding and definition of local features is imperative for prediction of latency in this type of task.

With this line of reasoning, a reexamination of the latency data sets was felt to be in order, and in fact revealed a slightly different categorization of distractor conditions, viewed post hoc. The HCS analysis procedure is well suited for this recategorization since the raw data from the original stimulus symbol presentations for each subject comprises a matrix of response times for all target-distractor pairs. By collapsing all subjects' responses into a single matrix of mean latencies (one matrix for helicopter symbols and one for the missile symbols), these can be analyzed using the HCS procedure to derive clusters to show which groups are performing at what level of interference. Figure 16 shows the HCS output of such an analysis for the helicopters, and Figure 17 the same for the missiles.

The new clusterings provide the needed insight into local feature definition. The previous categorizations did not anticipate the critical role of local feature similarity (conditions M, 2M, 3M, and L, detailed in the design section above) as it relates to all global clusters. It was assumed that global precedence would prevail (provide greatest interference) before the influence of any local features. Since

Connectedness Method		7		11		2		6		3		4		5		1		13		17		10		12
Weak	25.0	.		.		X	X	X		.		.		.		.		.		.		.		.
	22.3	.		.		X	X	X		.		.		X	X	X		.		.		.		
	18.8	.		.		X	X	X		.		X	X	X		X	X	X		.		.		.
	18.7	.		.		X	X	X		.		X	X	X	X	X	X	X		.		.		.
	18.2	.		.		X	X	X	X	X		X	X	X	X	X	X	X		.		.		.
"Strength" or "Value"	18.1	.		.		X	X	X	X	X		X	X	X	X	X	X	X	X	X		.		.
	17.7	.		.		X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X		.
	16.7	.		.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		.
	16.6	.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		.
	16.2	.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Strong	15.8	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

End of Method

Figure 16. Hierarchical Clustering Scheme obtained on response latencies - Helicopter symbols.

Connectedness Method		5		3		4		10		6		7		8		9		1
Weak	20.6	.		.		X	X	X		.		.		.		.		.
	19.6	.		.		X	X	X		X	X	X		.		.		.
	17.6	.		.		X	X	X		X	X	X		.		X	X	X
	17.2	.		.		X	X	X	X	X	X	X		.		X	X	X
"Strength" or "Value"	17.1	.		X	X	X	X	X	X	X	X	X		.		X	X	X
	16.4	.		X	X	X	X	X	X	X	X	X	X	X		X	X	X
	15.9	.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Strong	15.6	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

End of Method

Figure 17. Hierarchical Clustering Scheme obtained on response latencies - Missile symbols.

the exposure time for the current task was more extended than for previous studies, the role of local features became prominent. The HCS on response latencies demonstrates that, in many cases, symbols linked by locally similar features, even though from different global categories, represent the greatest interference for target detection. For example, in Figure 16, (helicopters), symbols 2 and 6, followed by 2, 6, and 3 emerge as a cluster. Symbol 1 eventually becomes aligned with the old global 3 category (symbols 13, 17, and 10 - refer to Table 3). The original "M" or most distracting condition remains intact but it is second in level of distraction to the globally different/locally similar pairs. Essentially the HCS provides a way to recategorize the stimulus populations into more meaningful groups, which account for local feature definition. For the helicopter symbols, five categories are evident based on pairings of symbols from the HCS clusters. Some of these are intact from the old categories and some represent shifts. Table 13 lists the new categories for the helicopter symbols from most to least interfering conditions based on the HCS analysis. The new missile clusters follow a course similar to the latencies for the helicopters. Again a new globally different/locally similar category emerges which presents the most interference to target detection. In the case of the missile symbols, the previous "2M" or second most interfering category is now absorbed into the newly defined group. Table 14 lists the new missile category conditions. The original listings of global categories (Tables 3 and 4) were based on examinations of MDS space which provided global clusterings. It was projected that as distance between clusters increased, interference would decrease. The new scheme, formulating some subclusters, permits the importance of local features to emerge.

Using the new categories, revised one way ANOVAs were performed in the manner previously described, but using the category shifts. Tables 15 and 16 contain the helicopter and missile summaries, and Tables 17 and 18 show the contrasts between specific means. For both the helicopter and missile sets, F ratios were again significant, this time both at the $p < .001$ level of significance. More importantly, the log mean scores were aligned to reflect greater to lesser target distraction, with the newly defined globally different/locally similar category first. It is immediately obvious in examining the contrasts from both symbol sets that these show a more meaningful trend and are descriptive of the actual performance. In the case of symbols which are very distant in the MDS space, with both global and local dissimilarity, the response times are nearly the same as the target alone condition. The critical symbol combinations which provide the greatest interference to search performance (and thus are the best predictors of detection latency) are, mainly, locally similar pairs, and then globally and locally similar pairs.

Table 13.

Identified Symbol Categorizations Delineating Global and Local Features, from Most to Least Interference.

Most Interference	Globally different/Locally similar
	Globally similar/Locally similar (same as M before)
	Globally similar/Locally different (previous 2M)
	Globally different/Locally different-close in MDS space
Lease Interference	Globally different/Locally different-distant in MDS space

Table 14.

Identified Symbol Categorizations Delineating Global and Local Features, from Most to Least Interference (Missile Symbols).

Most Interference	Globally different/Locally similar
	Globally similar/Locally similar (previous 2M)
	Globally different/Locally different-close in MDS space
Least Interference	Globally different/Locally different-distant in MDS space

Table 15.

ANOVA Summary - Response Latencies, Helicopter Symbols (Revised).

Source	df	MS	F
Target-Distractor Interference	5	.02507	5.42 *
Error	75	.00463	

* $p < .001$

Table 16.

ANOVA Summary - Response Latencies, Missile Symbols (Revised).

Source	df	MS	F
Target-Distractor Interference	4	.01662	5.64 *
Error	60	.00295	

* $p < .001$

Table 17.

Planned Contrasts between Mean Response Latencies Using Duncan's Multiple Range Test, Helicopter Symbols: Revised (α=.05).

Description		Mean Response Latency (log)
Control Condition (C)		.12484
Target-Distractor Conditions (TD)		.18118
Individual Target-Distractor Conditions		
Globally different/Locally similar	(GD/LS)	.23166
Globally similar/Locally similar	(GS/LS)	.20715
Globally different/Locally different-close	(GD/LDC)	.15872
Globally different/Locally different-distant	(GD/LDD)	.15563
Globally similar/Locally different	(GS/LD)	.15274

Contrast		Critical Value	
1. C - TD	= .05634	.04811	significant
2. GD/LS-C	= .10682	.05439	significant
3. GS/LS-C	= .08231	.05345	significant
4. GD/LDC-C	= .03388	.05226	n.s.
5. GD/LDD-C	= .03079	.05061	n.s.
6. GS/LD-C	= .02790	.04811	n.s.
7. GD/LS-GS/LS	= .02451	.04811	n.s.
8. GD/LS-GD/LDC	= .07294	.05061	significant
9. GD/LS-GD/LDD	= .07603	.05226	significant
10. GD/LS-GS/LD	= .07892	.05345	significant
11. GS/LS-GD/LDC	= .04843	.04811	significant
12. GS/LS-GD/LDD	= .05152	.05061	significant
13. GS/LS-GS/LD	= .05441	.05226	significant
14. GD/LDC-GD/LDD	= .00309	.04811	n.s.
15. GD/LDC-GS/LD	= .00598	.05061	n.s.
16. GD/LDD-GS/LD	= .00289	.04811	n.s.

Table 18.

Planned Contrasts between Mean Response Latencies Using Duncan's Multiple Range Test, Missile Symbols: Revised (α = .05).

Description		Mean Response Latency (Log)
Control Condition (C)		.13649
Target-Distractor Conditions (TD)		.17931
Individual Target-Distractor Conditions		
Globally different/Locally similar	(GD/LS)	.21221
Globally similar/Locally similar	(GS/LS)	.19196
Globally different/Locally different-close	(GD/LDC)	.17082
Globally different/Locally different-distant	(GD/LDD)	.14226

Contrast		Critical Value	
1.	C-TD = .04282	.03840	significant
2.	GD/LS-C = .07572	.04266	significant
3.	GS/LS-C = .05547	.04171	significant
4.	GD/LDC-C = .03433	.04040	n.s.
5.	GD/LDD-C = .00577	.03840	n.s.
6.	GD/LS-GS/LS = .02025	.03840	n.s.
7.	GD/LS-GD/LDC = .04139	.04040	significant
8.	GD/LS-GD/LDD = .06995	.04171	significant
9.	GS/LS-GD/LDS = .02614	.03840	n.s.
10.	GS/LS-GD/LDD = .04970	.04040	significant
11.	GD/LDC-GD/LDD = .02856	.03840	n.s.

GENERAL DISCUSSION

Previous studies investigating the efficacy of the global precedence concept to explain perceptual processing (Navon, 1977, 1981; Kinchla & Wolf, 1979; Martin, 1979, etc.) have focused on artificially constructed stimuli to insure the unambiguous definition of global and local features, and have used threshold detection tasks. Only recently have extensions of the global precedence work been developed (Hughes, Layton, Baird, & Lester, 1984) to examine its utility by using other types of stimuli. The current study has been an attempt to apply scaling techniques to an existing database of predefined symbols, and to elicit the global and local features as they already reside in the images. Limited success is encountered in using this approach. The global/local distinctions are valuable in describing images which are perceptually close, and thus can be predictive of greater interference in detection performance. However, the scaling method (MDS) used is not as precise as is required to completely describe local features, which are an important determinant of perceptual processing time in the search and locate task used in this study.

The hypotheses, as stated in the introductory section, were directed toward differentiating target-alone performance from target detection with various types of distractor symbols. Clear differentiation was achieved for the response latency measure (hypothesis 1a and 2a), but performance accuracy (hypothesis 1b and 2b) only suggests a trend. As opposed to simple detection threshold studies, a search task requires

more time, and subjects typically have the capability to select the correct answer. The response latency seems to be a more effective measure than performance accuracy for discrimination of target-distractor combinations which delay target selection.

Since the scaling techniques do not provide the needed detail to allow complete one to one correspondence between clusters and response latencies, it appears that the MDS analysis is only a first step toward definition of image features which will be predictive of detection performance. If distance between symbols in the MDS space were predictive by itself, the distances matrix obtained during the scaling analysis would produce a high negative correlation as a function of performance time. That is, as distance between symbols increases, time for response should decrease. In fact, it does not. Pearson r values of r= -.06 (helicopter) and r= .36 (missile) indicates virtually no relationship between the MDS distances and response time. This is because the needed final categorizations of symbols by local features are not captured by the MDS clusters alone. Further definition of local elements are needed to reveal the actual critical clusters for impacting the response measure for this type of task.

This is not to imply that the global precedence concept cannot play a valuable role in describing image structure in a way that will allow useful prediction. The data from this investigation clearly demonstrate that images which are globally and locally similar will interfere significantly with each other in a target detection task. However, further refinement of a priori scaling procedures will be required in order to elicit local features. One possible approach to this would be to combine known images with well defined global and local features with

the database of images projected for study, during the similarity judgment phase. In this way prior knowledge would be used to create the additional locally similar category because like symbols from the test database would cluster with the "planted" images of known local features. In the current study, only by looking post hoc at the performance data matrix can visual inspection reveal the obvious regarding local feature similarity. It is now clear that this plays a major role in perceptual performance for symbol target search tasks.

SUMMARY

The concept of global precedence in perceptual processing in the psychological literature was evaluated in terms of its efficacy in predicting detection of map symbols in current use. The essence of the global precedence position is that perception proceeds temporally, through stages, from the recognition of global features to more local, fine grained analysis of individual elements. This investigation is a departure from previous studies of the concept, used real world stimuli in a detection task instead of artificially constructed, abstract stimulus images. The extension of the global precedence idea to a task analogous to those in applied settings was done to allow a broader interpretation of the global precedence concept; a parsimonious way of explaining detection performance for the search and locate task used also was expected.

In the procedure, selected map symbols were categorized according to global and local features, using MDS techniques as well as hierarchical cluster analysis. Then a detection task was performed using the symbols against a homogeneous map background. The hypotheses under consideration were:

> Hypothesis 1a: The speed of target symbol identification will be faster for a single target condition than for a target plus distractor condition.

> Hypothesis 1b: The accuracy of target symbol identification will be greater in the single target condition than in the target plus distractor condition.

Hypothesis 2a: The speed of target symbol identification will be affected by the structural relation of a distractor symbol to the target symbol. Speed of target identification will be fastest when the target is from a different global category than the distractor, and slowest when the distractor is from the same global category.

Hypothesis 2b: The accuracy of target symbol identification will be affected by the structural relation of a distractor symbol to the target symbol. Accuracy of target identification will be greater when the distractor is from a different global category than when the distractor is from the same global category.

The response latency and accuracy measures from the detection study were analyzed using a one-way repeated measures ANOVA followed by planned comparisons between target-distractor category means using Duncan's Multiple Range Test. Findings generally offered strong support for the hypotheses 1a and 2a, for response latency, but somewhat weaker support for the accuracy measures included in hypotheses 1b and 2b. The initial analysis, although discriminating among target-distractor conditions in detection performance, did not reflect the impact of global precedence in all cases. A follow-up clustering of response latencies using Hierarchical Cluster Scheme (HCS) analysis revealed that local feature similarity played a more prominent role in discriminating symbol groups than was originally suspected. When revisons to the original groupings were made to adjust for this local similarity factor, revised ANOVAs and comparisons allowed for statistically significant and meaningful description of the performance.

The global precedence concept is a viable and useful one in describing symbol populations in existence as long as the a priori scaling procedures used to derive global and local features can provide the definition required to replicate the work done with the previously used

artificially constructed images. In this particular study, which used two actual symbol sets, helicopter and missile map symbols, the missile symbols, being fewer in number and more homogeneous in appearance, were easier to scale and interpret. The helicopter group, being larger and more diverse, resulted in difficulties in the elicitation of global and local features, although both symhol groups provided the same general trends. Clearly the use of pre-existing symbol sets must be scaled precisely, perhaps in conjunction with other, more abstract but well defined images, that are known in their global and local features. In this way a fine discrimination of new symbol features can be obtained on any symbol population to validly predict performance.

REFERENCES

Atkinson, R. C., and Shiffrin, R. M. Human Memory: A proposed system and its control processes. In The Psychology of Learning and Motivation. Vol. 2, G. H. Bowen & J. T. Spence (Eds.) New York: Academic Press, 1968.

Attneave, F. Some informational aspects of visual perception. Psychological Review, 1954, 61, 183-193.

Bjork, E. L. and Murray, J. T. On the nature of input channels in visual processing, Psychological Review, 1977, 84, 472-484.

Bloomfield, J. R. Visual search in complex fields: size differences between target disc and surrounding discs. Human Factors, 1972, 14, 139-148.

Boer, L. C., and Keuss, P.J.G. Global precedence as a postperceptual effect: An analysis of speed-accuracy tradeoff functions. Perception & Psychophysics, 1983, 31, (4) 358-366.

Breitmeyer, B.G., and Ganz, L. Implications of sustained and transient channels for theories of visual pattern masking, saccadic suppresion, and information processing. Psychological Review, 1976, 83, 1-36.

Broadbent, D. E. The hidden preattentive process. American Psychologist, 1977, 32, (2), 109-118.

Calis, G. and Leeuwenberg, E. Grounding the figure. Journal of Experimental Psychology: Human Perception and Performance, 1981, 7, 1386-1397.

Carroll, J. D., and Wish, M.E. Multidimensional perceptual models and measurement methods. In Handbook of Perception, Vol II. Psychophysical judgment and measurement. San Francisco: Academic Press, 1974, 391-447.

Convey, J. A Primer on Simultaneous Inference Procedures for Multiple Contrasts in the Analysis of Variance. Washington, DC: Catholic University of America, 1980.

Eriksen, C. W. Location of objects in a visual display as a function of the number of dimensions on which the objects differ. Journal of Experimental Psychology, 1952, 44 (2), 56-60.

Eriksen, C. W. Object location in a complex perceptual field. Journal of Experimental Psychology, 1953, 45, 126-132.

Eriksen, C. W. Partitioning and saturation of visual displays and efficiency of visual search. Journal of Applied Psychology, 1955, 39 (2), 73-77.

Eriksen, C. W., and Eriksen, B. A. Target redundancy in visual search: Do repetitions of the target within the display impair processing? Perception & Psychophysics, 1979, 26 (3) 195-205.

Eriksen, C. W., and Schultz, D. W. Information processing in visual search: A continuous flow conception and experimental results. Perception & Psychophysics, 1979, 25, 249-263.

Estes, W. K. Interactions of signal and background variables in visual processing. Perception & Psychophysics, 1972, 12, 278-286.

Estes, W. K. Redundancy of noise elements and signals in visual detection of letters. Perception & Psychophysics, 1974, 16, 53-60.

Garner, W. R. Assymetric interactions of stimulus dimensions in perceptual information processing. In Proceedings of the conference on Perception and Cognition, T. Tighe (Ed.), Hillsdale, N Y: Erlbaum, 1983.

Getty, D. J., Swets, J. A., Swets, J. B., and Green, D. M. On the prediction of confusion matrices from similarity judgments. Perception & Psychophysics, 1979, 26 (1) 1-19.

Gibson, E. J. Principles of perceptual learning and development. New York: Appleton, 1969.

Grice, G. R., Canham, L., and Boroughs, J. M. Forest before trees? It depends on where you look. Perception and Psychophysics, 1983, 33 (2) 121-128.

Haber, R. N., and Hershenson, M. The Psychology of Visual Perception. New York: Holt, Rinehart, and Winston, 1980.

Hoffman, J. E. Interaction between global and local levels of a form. Journal of Experimental Psychology: Human Perception and Performance, 1980, 6, 222-234.

Hughes, H. C., Layton, W. M., Baird, J. C., and Lester, L. S. Global precedence in visual pattern recognition. Perception & Psychophysics, 1984, 35 (4) 361-371.

James, W. The principles of psychology. New York: Holt, Rinehart, and Winston, 1890.

Johnson, S. C. Hierarchical clustering schemes. Psychometrika, 1967, 32, (3) 241-254.

Johnston, S. C., Peck, P., and Landee, B. M. Tactical Symbology Catalog. Research Product 83-6, prepared for U S Army Research Institute, by Perceptronics, Inc., under contract DAHC 19-78-C-0018, May, 1983. (AD A132 625)

Julesz, B. Perceptual limits of texture discrimination and their implications to figure-ground separation. In Formal theories of perception. E. Leeuwenberg, (Ed.), New York: Wiley, 1978.

Kinchla, R. A., Solis-Macias, V., and Hoffman, J. Attending to different levels of structure in a visual image. Perception & Psychophysics, 1983, 33 (1), 1-11.

Kinchla, R. A., and Wolf, J. The order of visual processing: "top-down", "bottom-up", or "middle-out". Perception & Psychophysics, 1979, 25 (3) 225-231.

King, M. C., Gruenewald, P. J., and Lockhead, G. R. Classifying related stimuli. Journal of Experimental Psychology: Human Learning and Memory, 1978, 4, 417-427.

Koffka, K. Principles of Gestalt Psychology, New York: Harcourt, Brace, 1935.

Kruskal, J.B. Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. Psychometrika, 1964, 29, 1-27.

Kruskal, J. B., and Wish, M. E. Multidimensional Scaling. Beverly Hills, California, 1978.

Larsen, A., and Bundesen, C. Size scaling in visual pattern recognition. Journal of Experimental Psychology: Human Perception and Performance, 1978, 4, 1-20.

Mach, E. The analysis of sensations. (Rev. 5th Edition, C.M. Williams, trans). New York: Dover Publications, 1959 (originally published, 1895).

Martin, M. Local and global processing: The role of sparsity. Memory and Cognition, 1979, 7, 476-484.

McClelland, J. L., and Miller, J. Structural factors in figure perception. Perception & Psychophysics, 1979, 26 (3), 221-229.

McLean, J. P. Perspectives on the forest and trees: The precedence of parts and wholes in visual information processing. 1978 Doctoral dissertation, University of Oregon: Dissertation Abstracts International, 1979, 39, 6162B-6163B.

Miller, J. Global precedence in attention and decision. Journal of Experimental Psychology: Human Perception and Performance. 1981, 7, 1161-1174, (a).

Miller, J. Global precedence: Information availability or use? Reply to Navon. Journal of Experimental Psychology: Human Perception and Performance, 1981, 7, 1183-1185, (b).

Navon, D. Forest before trees: The precedence of global features in visual perception. Cognitive Psychology, 1977, 9, 353-383.

Navon, D. The forest revisited: More on global precedence. Psychological Research, 1981, 43, 1-32, (a).

Navon, D. Do attention and decision follow perception? Comment on Miller. Journal of Experimental Psychology: Human Perception and Performance, 1981, 7, 1175-1182, (b).

Navon, D. How many trees does it take to make a forest? Perception, 1981, 43, 192-210, (c).

Navon, D., and Norman, J. Does global precedence really depend on visual angle? Journal of Experimental Psychology: Human Perception and Performance, 1983, 9, (6) 955-965.

Neisser, U. Cognitive Psychology. New York: Appleton-Century-Crofts, 1967.

Pedhazur, E. J. Multiple Regression in Behavioral Research. New York: Holt, Rinehart and Winston, 1980, 296-304.

Peterson, M.A., and Hochberg, J. Opposed set measurement procedure: A quantitative analysis of the role of local cues and intention in form perception. Journal of Experimental Psychology: Human Perception and Performance, 1983, 9 (2), 183-193.

Pomerantz, J., Sager. L., and Stoever, R. Perception of wholes and their component parts: Some configural superiority effects. Journal of Experimental Psychology: Human Perception and Performance, 1977, 3, 422-435.

Robertson, L. C., and Palmer, S. E. Holistic processes in the perception and transformation of disoriented figures. Journal of Experimental Psychology: Human Perception and Performance, 1983, 9 (2) 202-214.

Rumelhart, D. E. A multicomponent theory of the perception of briefly exposed visual displays. Journal of Mathematical Psychology, 1970, 7, 191-218.

Selfridge, O. Pandemonium: A paradigm for learning. In Symposium on the mechanization of thought processes. London: Her Majesty's Stationery Office, 1959.

Shepard, R.N. Psychological representation of speech sounds. In Human Communication: A Unified View, edited by David and P. Denes, New York: McGraw-Hill, 1972.

Takane, Y., Young, F., and deLeeuw, J. Nonmetric individual difference scaling: An alternating least squares method with optimal scaling features. Psychometrika, 1977, 42(1), 7-67.

Triesman, A. M., and Gelade, G. A. A feature-integration theory of attention. Cognitive Psychology, 1980, 12, 97-136.

Ward, L. M. Determinants of attention to local and global features of visual forms. Journal of Experimental Psychology: Human Perception and Performance, 1982, 8, 562-581.

Winer, B. Statistical Principles in Experimental Design, New York: McGraw-Hill, 1971, 149-305.

Wish, M.E., and Carroll, J. D. Concepts and applications of multidimensional scaling. Sensory Evaluation of Appearance of Materials, ASTM STP 545, American Society for Testing and Materials, 1973, 91-108.

Wong, E., and Weisstein, N. Sharp targets are detected better against a figure, and blurred targets are detected better against a background. Journal of Experimental Psychology: Human Perception and Performance, 1983, 9 (2), 194-202.

Young, F. W. Nonmetric multidimensional scaling: Recovery of metric information. Psychometrika, 1970, 35, 455-473.

Young, F., and Lewyckyj, R. ALSCAL-4 User's Guide. Carboro, NC: Data Analysis and Theory Associates, 1979.

APPENDIX

Instructions to Subjects for Phase II Symbol Detection Study

The Army Research Institute has recently been investigating the design and use of tactical military symbols. With the demands of battlefield planning and management to accomodate large amounts of data in a dynamic environment, effective symbols are required so that commanders and staff are able to "see the battlefield".

The task you are going to perform today is part of a research program aimed at providing effective designs for new symbols and methods for deciding among various symbols already in use. Your task today is to find a "target" on the screen, and push a button showing where you have found it.

First, you will see the target symbol by itself on the screen. Next, a "slide" will appear showing a map, and either one or two symbols placed on the map. Your job is to push one of the four buttons on your keyboard to show where you saw the target symbol:

TOP LEFT	TOP RIGHT
BOTTOM LEFT	BOTTOM RIGHT

Push one of the buttons as soon as you see where the target is. The slide will not be shown very long. Here is an example. (Press F1 to start example).

[Several practice trials shown, with option to repeat as needed.]